Ocean Circulation, Sea Level, and Climate Change

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Earth System Science @20 Symposium

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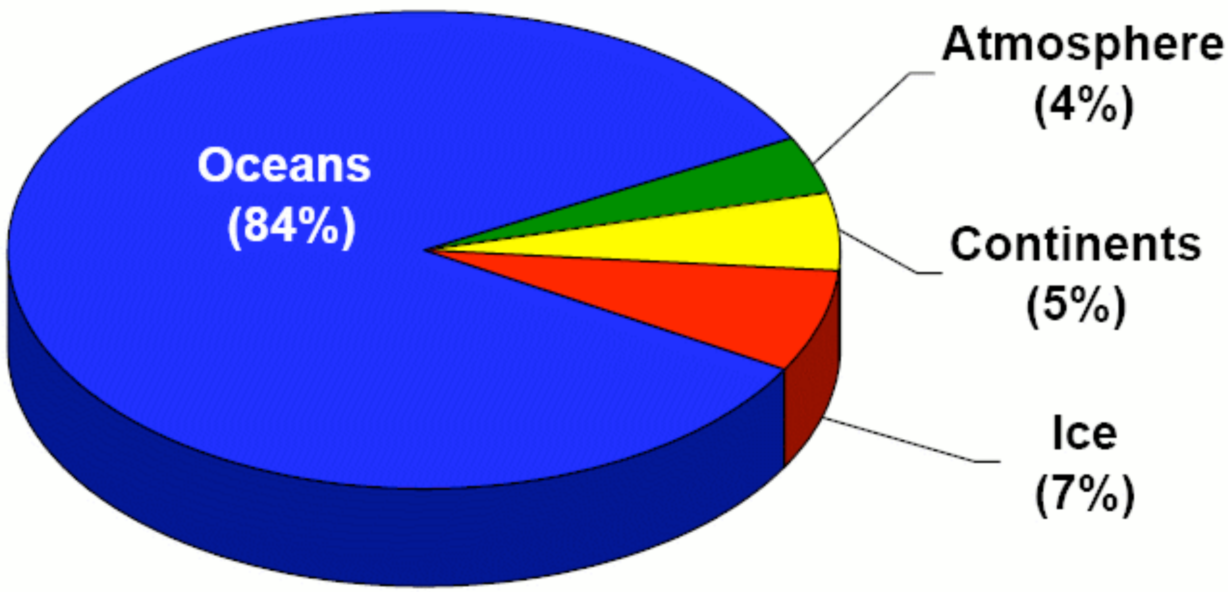
Planet Earth is the ocean planet...

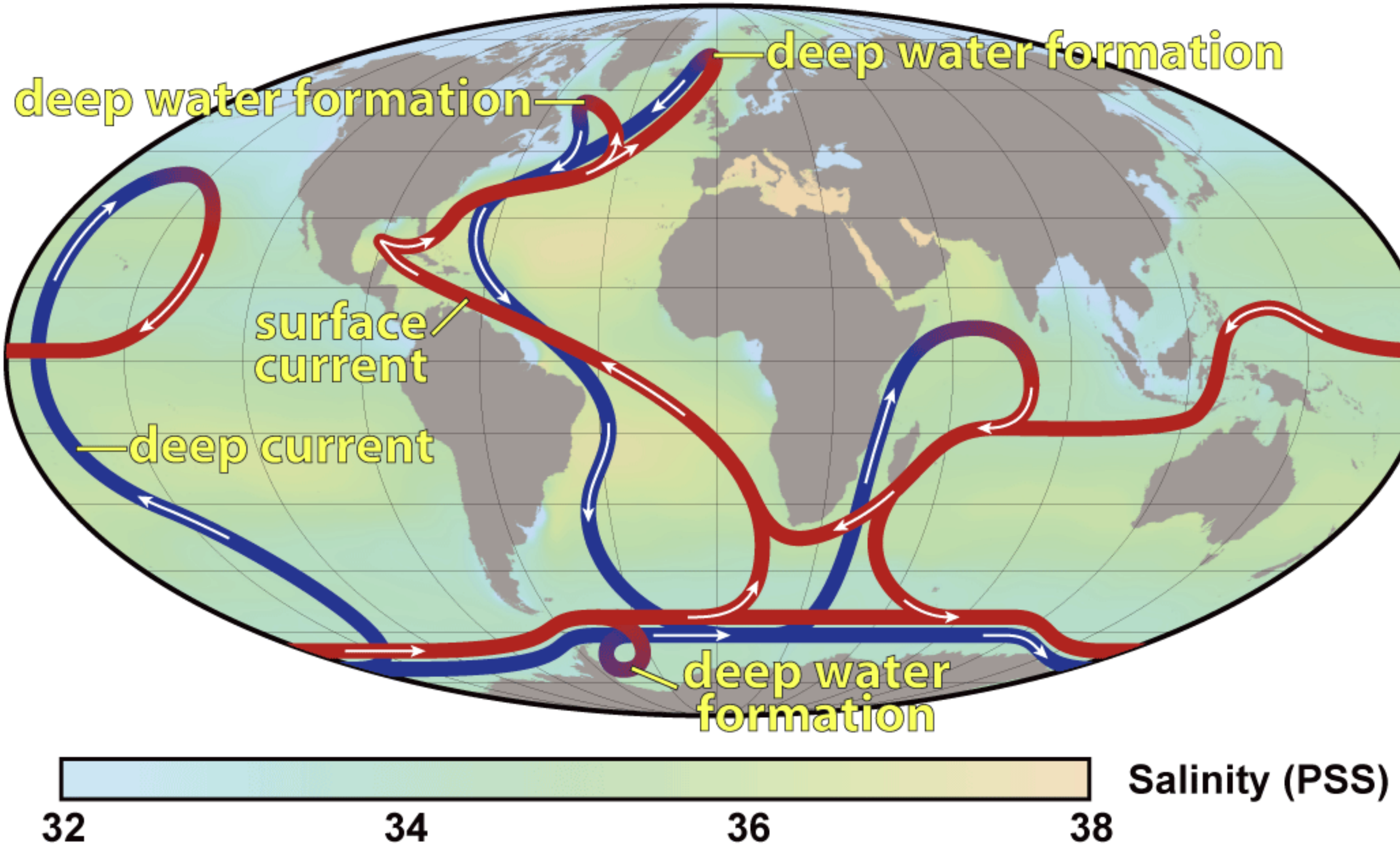
"How inappropriate to call this planet Earth, when clearly it is Ocean."
– Arthur C. Clarke –

Amount of heat absorbed by different parts of the Earth's climate system over the past 40 years

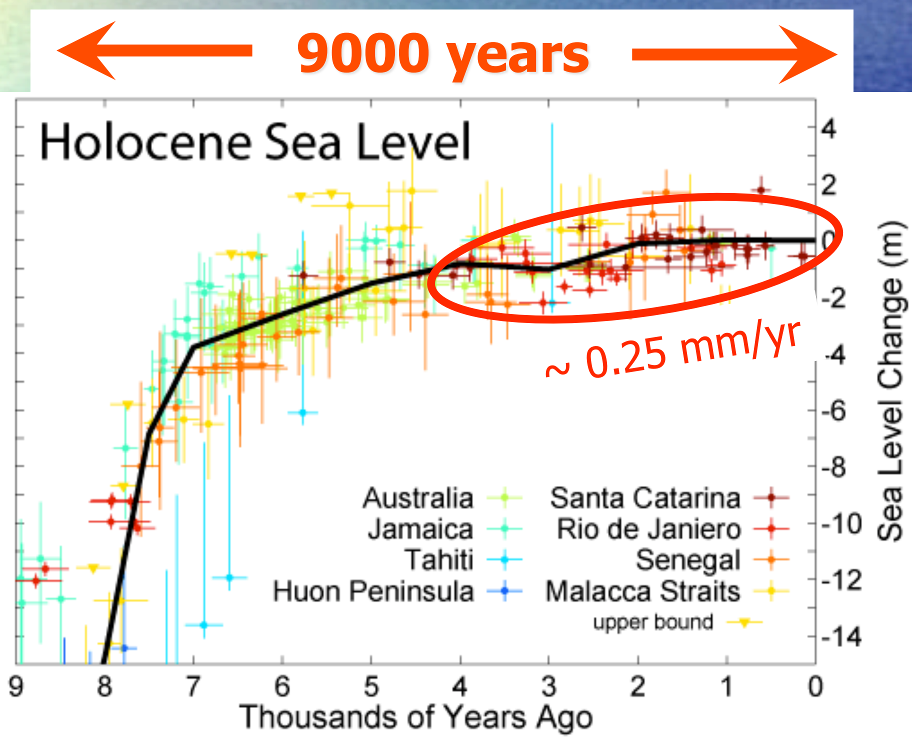


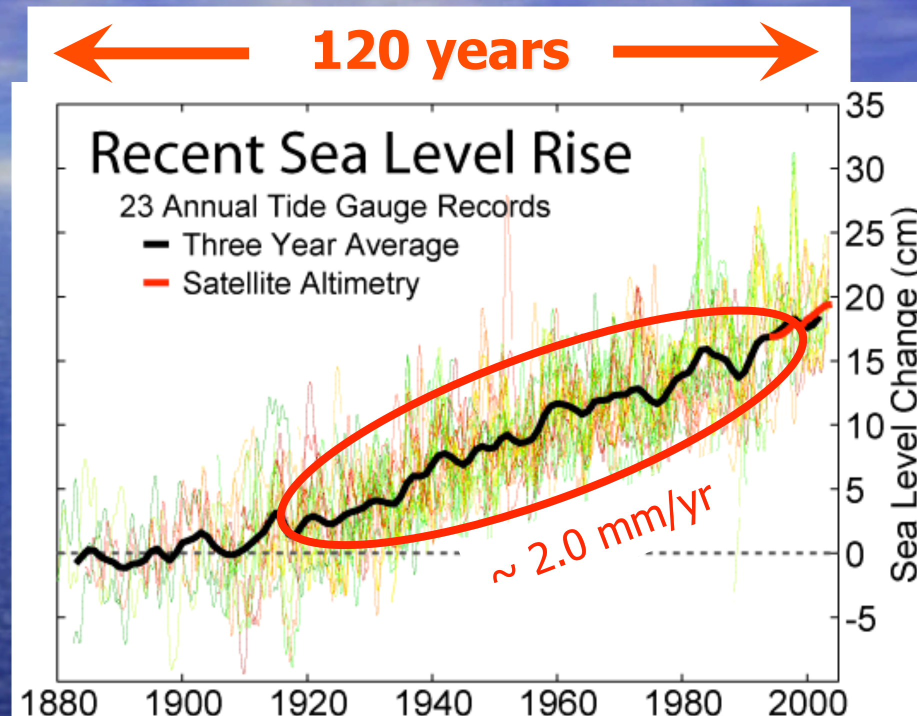
from *Levitus et al., 2004*

Thermohaline Circulation



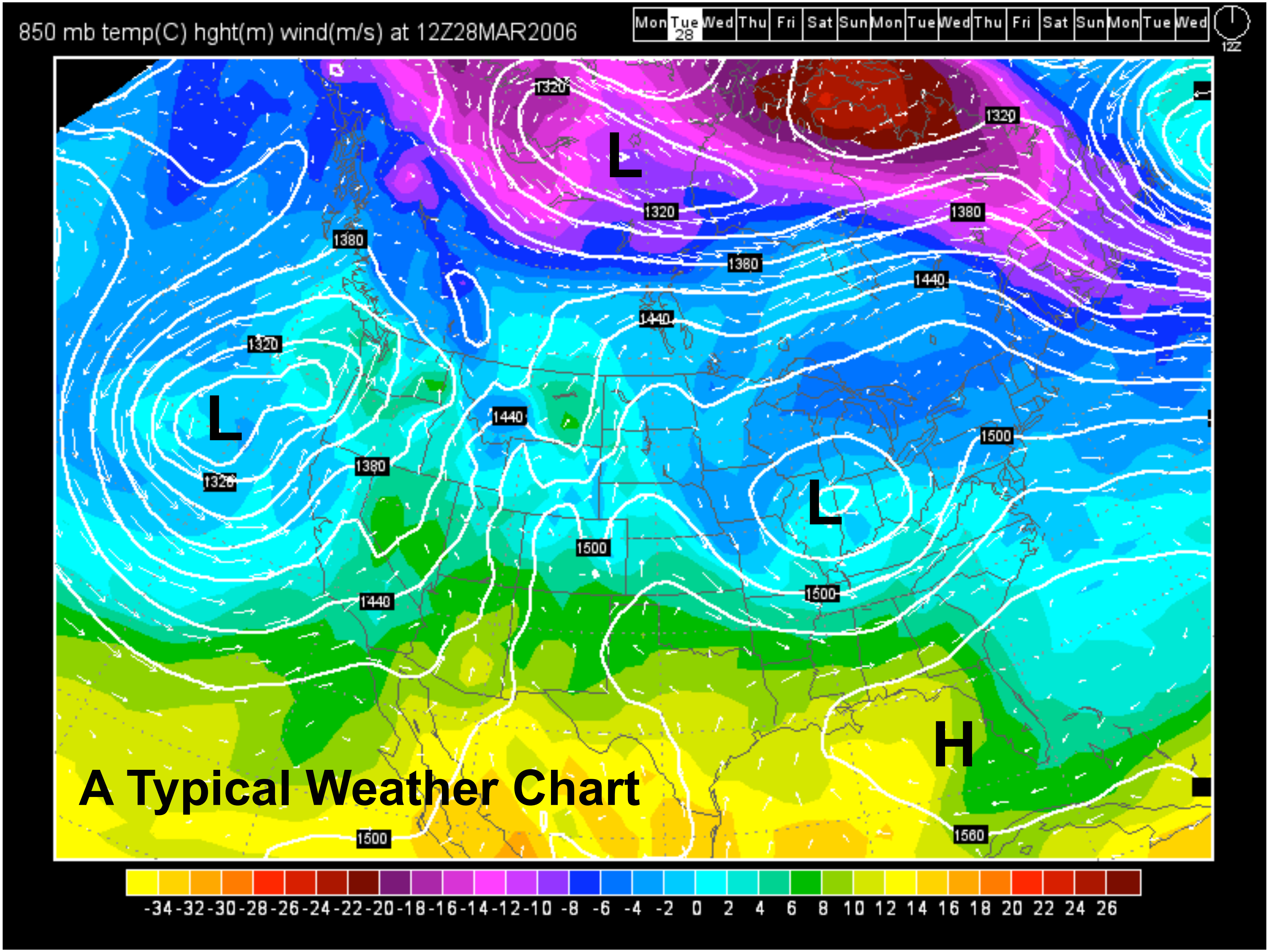
Historic Sea Level Rise





Recent rates of sea level rise are 10 times larger than historic rates.

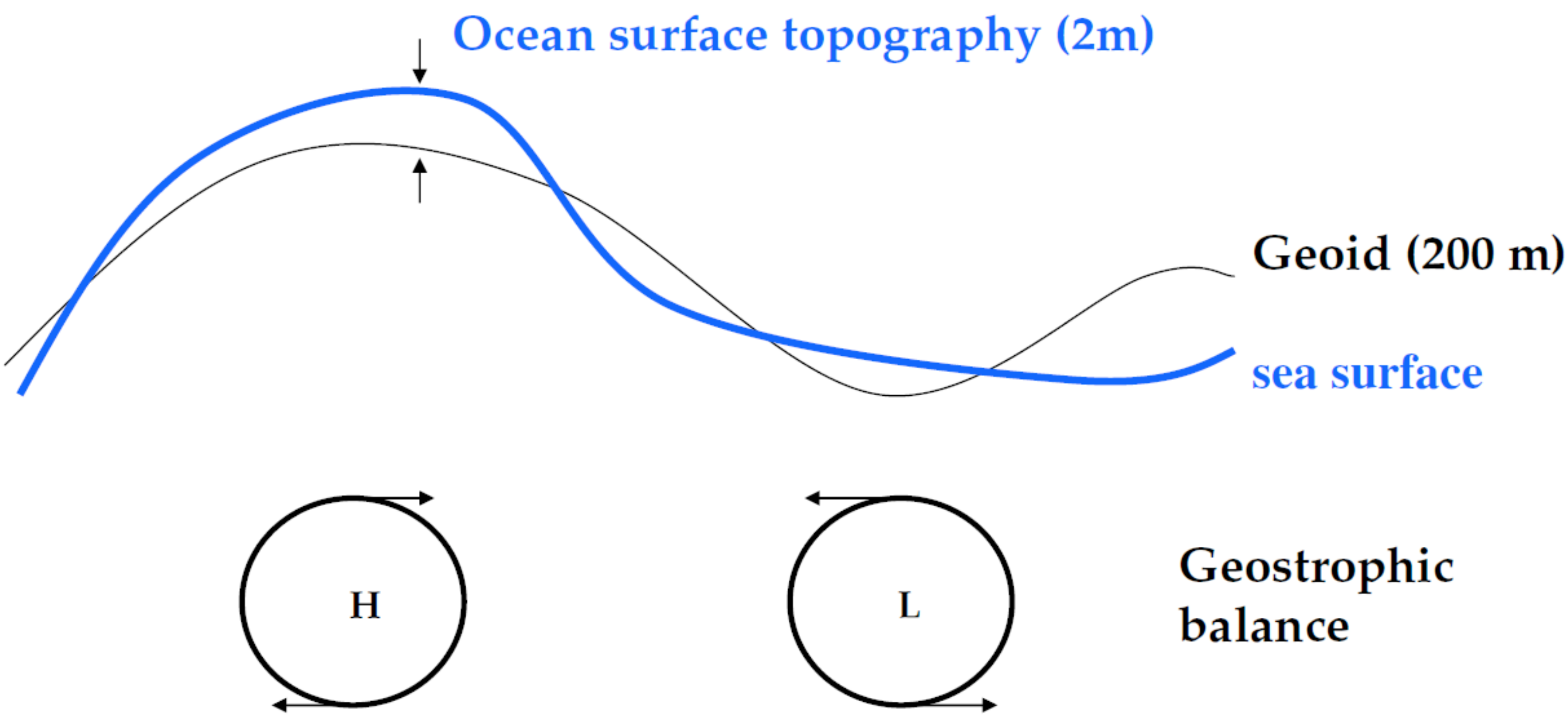
Plots by Robert A. Rohde for
Global Warming Art: http://www.globalwarmingart.com/

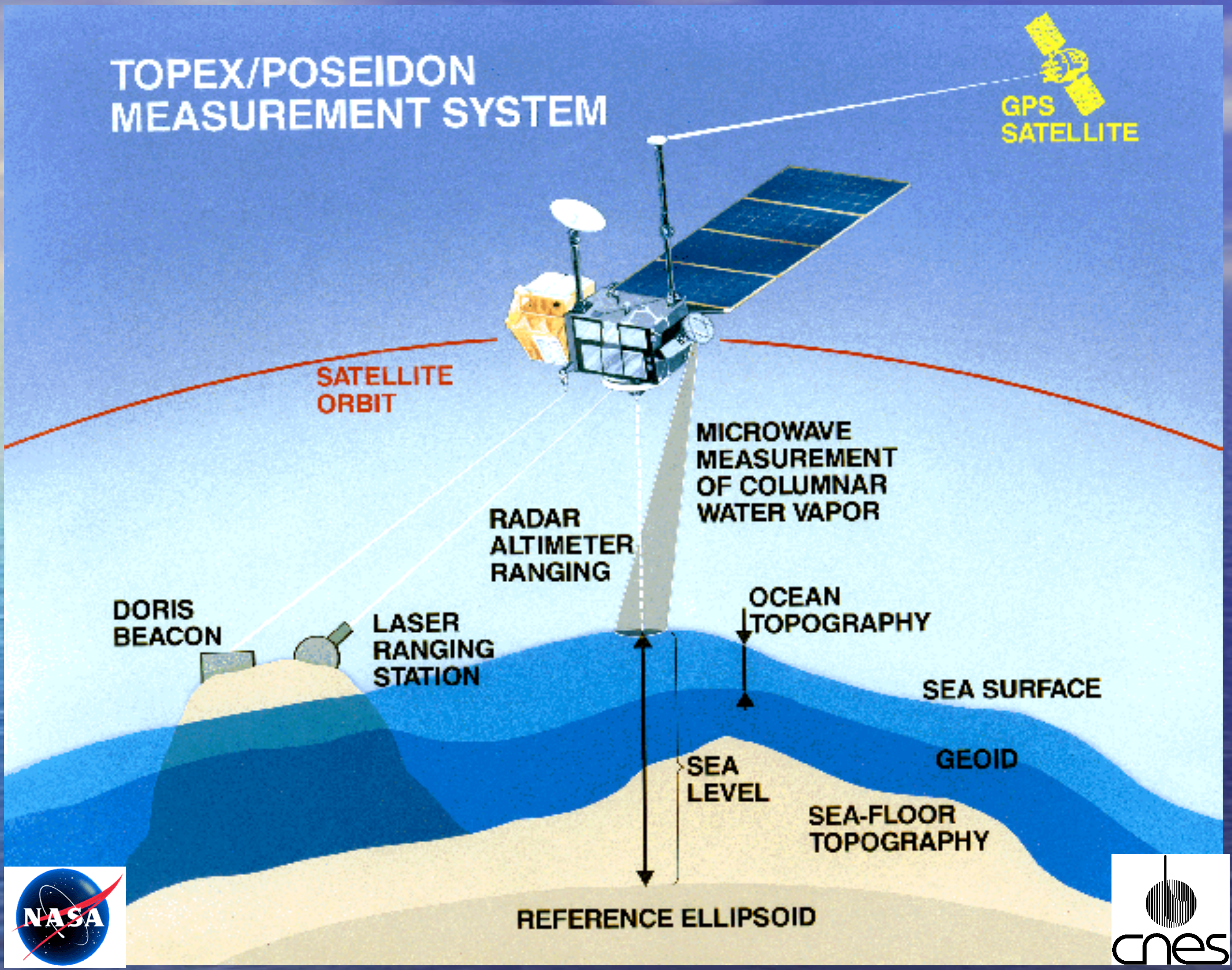

850 mb temp(C) hght(m) wind(m/s) at 12Z28MAR2006
Mon Tue 28 Wed Thu Fri Sat Sun Mon Tue Wed Thu Fri Sat Sun Mon Tue Wed
12Z
L
L
L
H
1320
1380
1440
1500
1560
A Typical Weather Chart
-34 -32 -30 -28 -26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26

Determining ocean circulation from space through

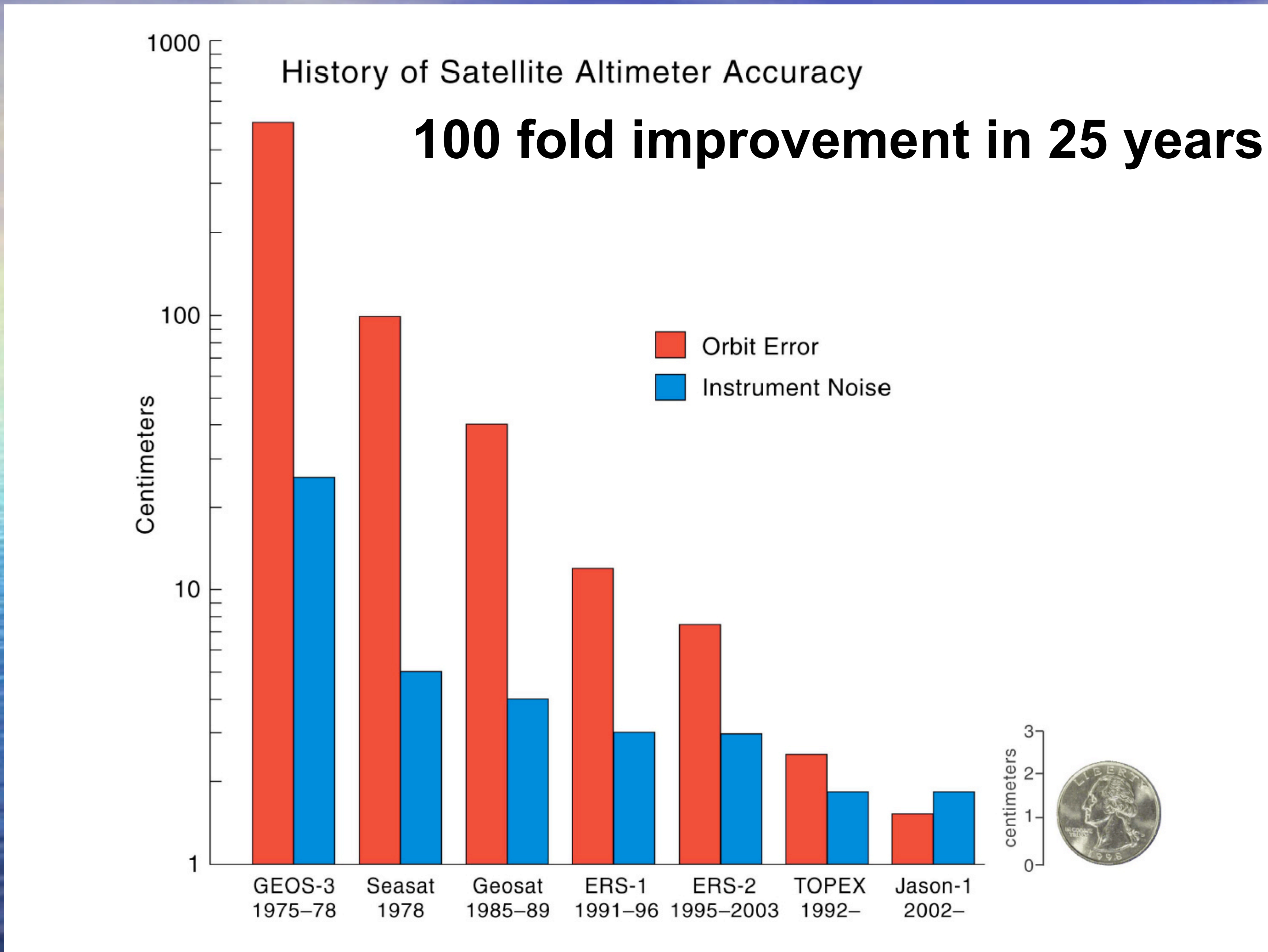
ocean surface topography,

the height of the sea surface above a surface of uniform gravity, the geoid.



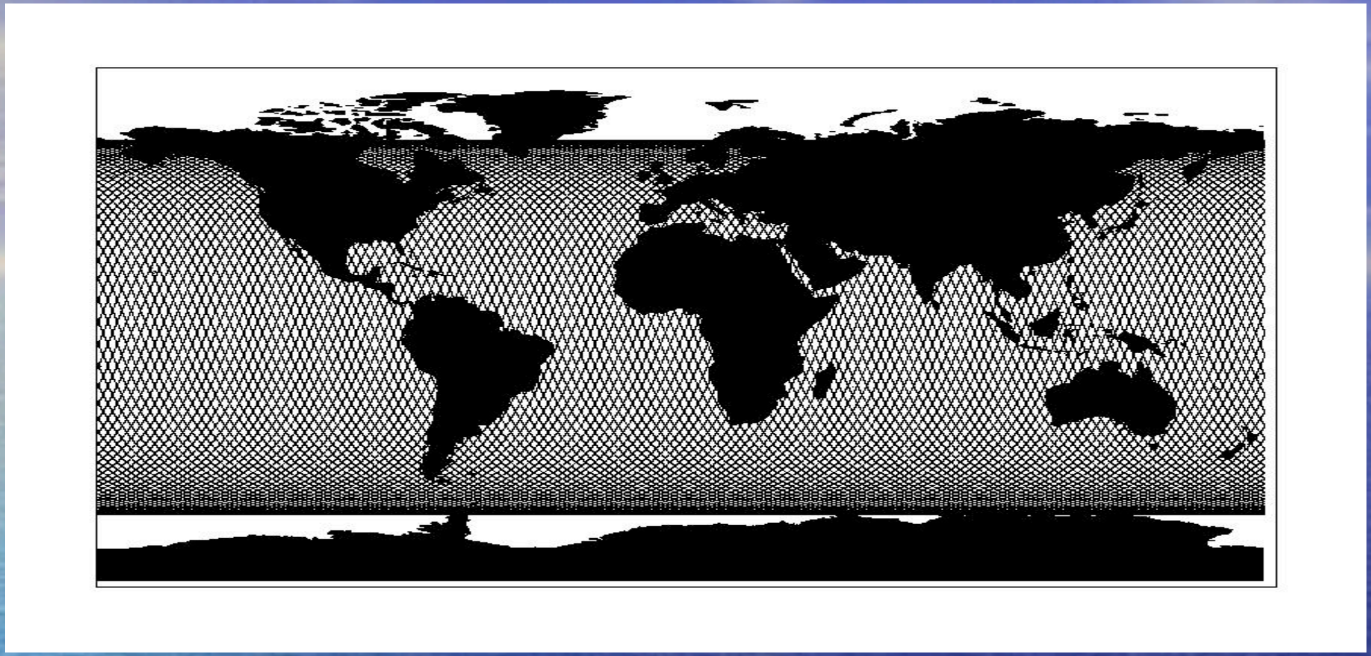


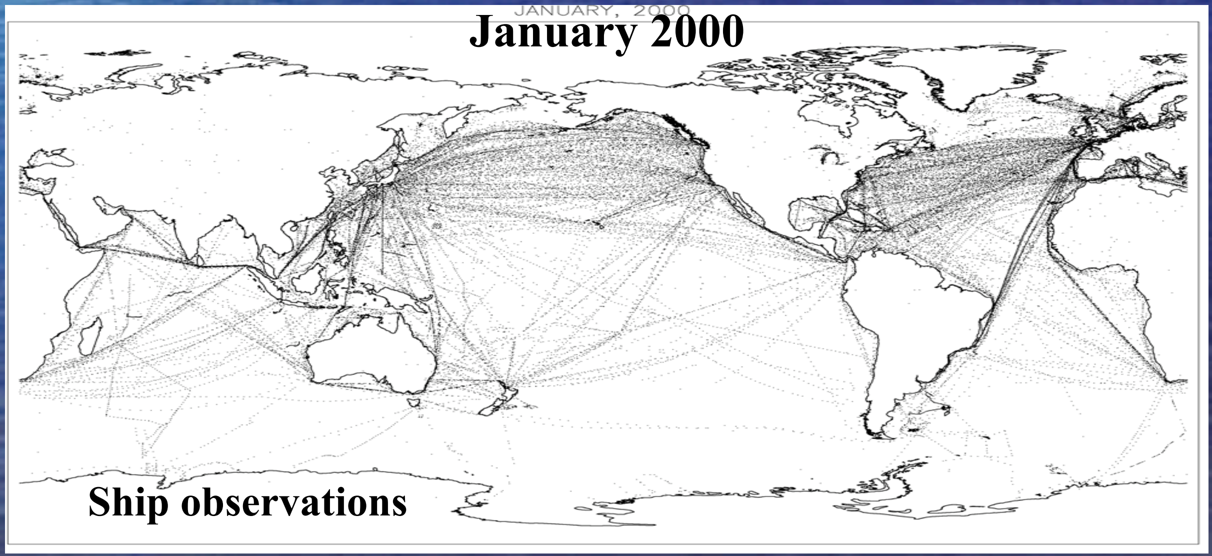
A quarter century of collaboration between NASA and CNES



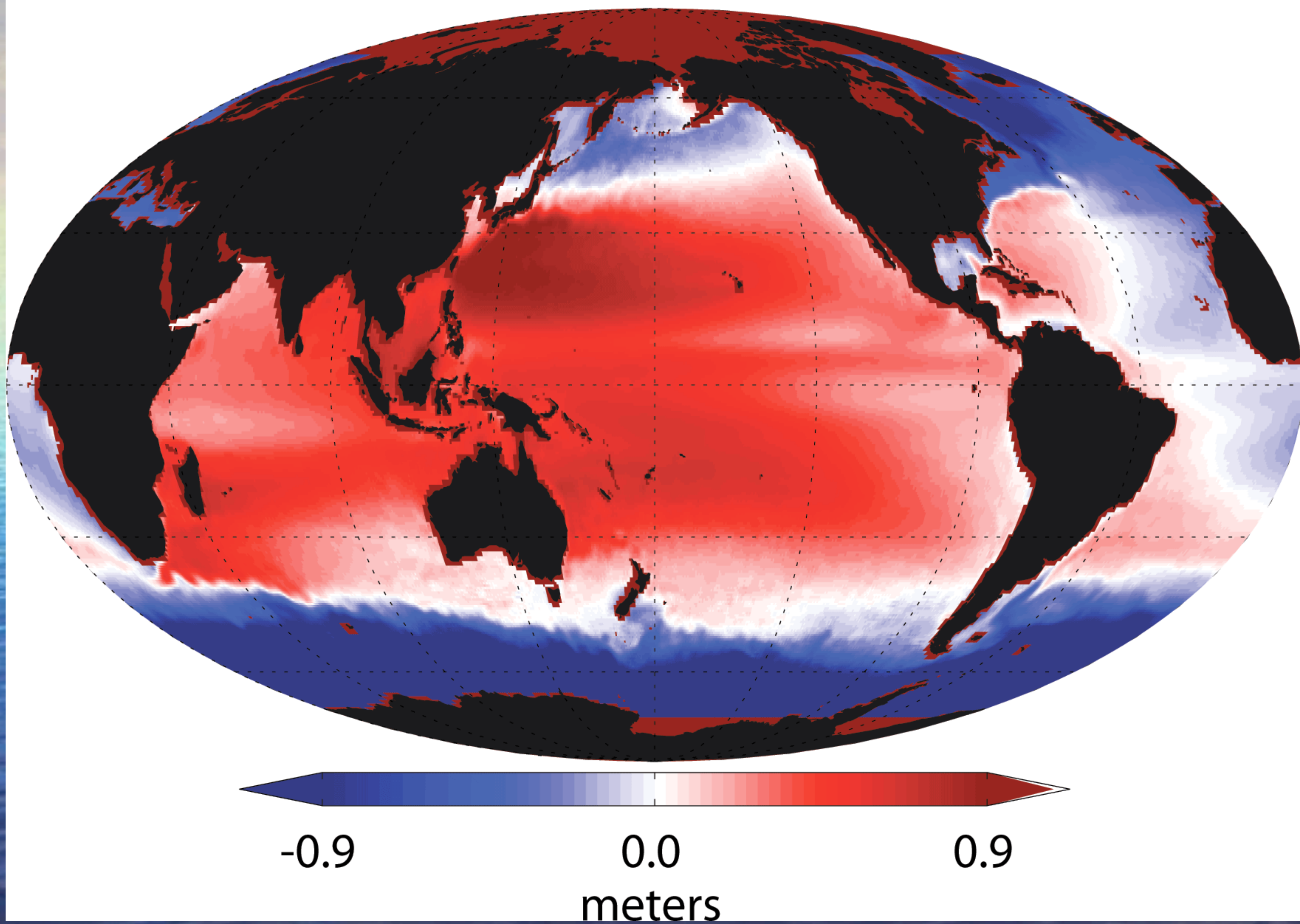
History of Satellite Altimeter Accuracy
100 fold improvement in 25 years
Centimeters
1000
100
10
1
Orbit Error
Instrument Noise
GEOS-3 1975–78
Seasat 1978
Geosat 1985–89
ERS-1 1991–96
ERS-2 1995–2003
TOPEX 1992–
Jason-1 2002–
centimeters
3
2
1
0

TOPEX/Poseidon ground track coverage every 10 days

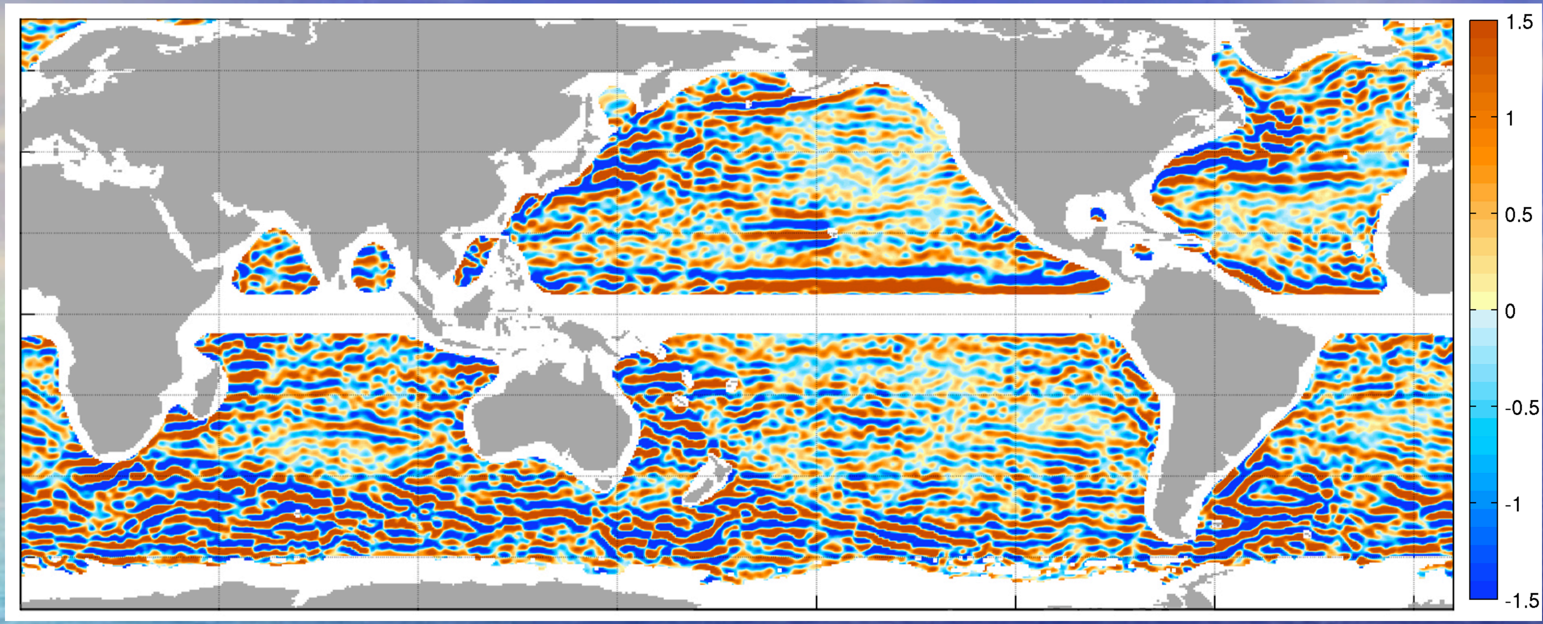




OCEAN SURFACE TOPOGRAPHY

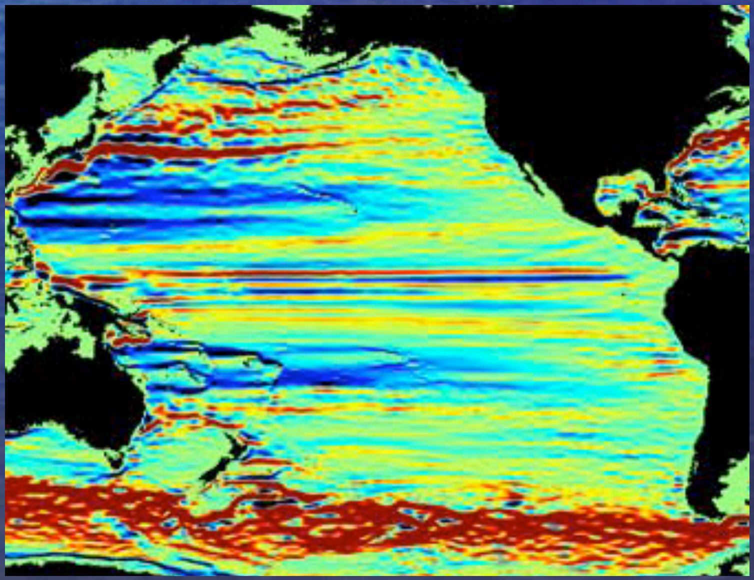


Eastward component of ocean surface current velocity

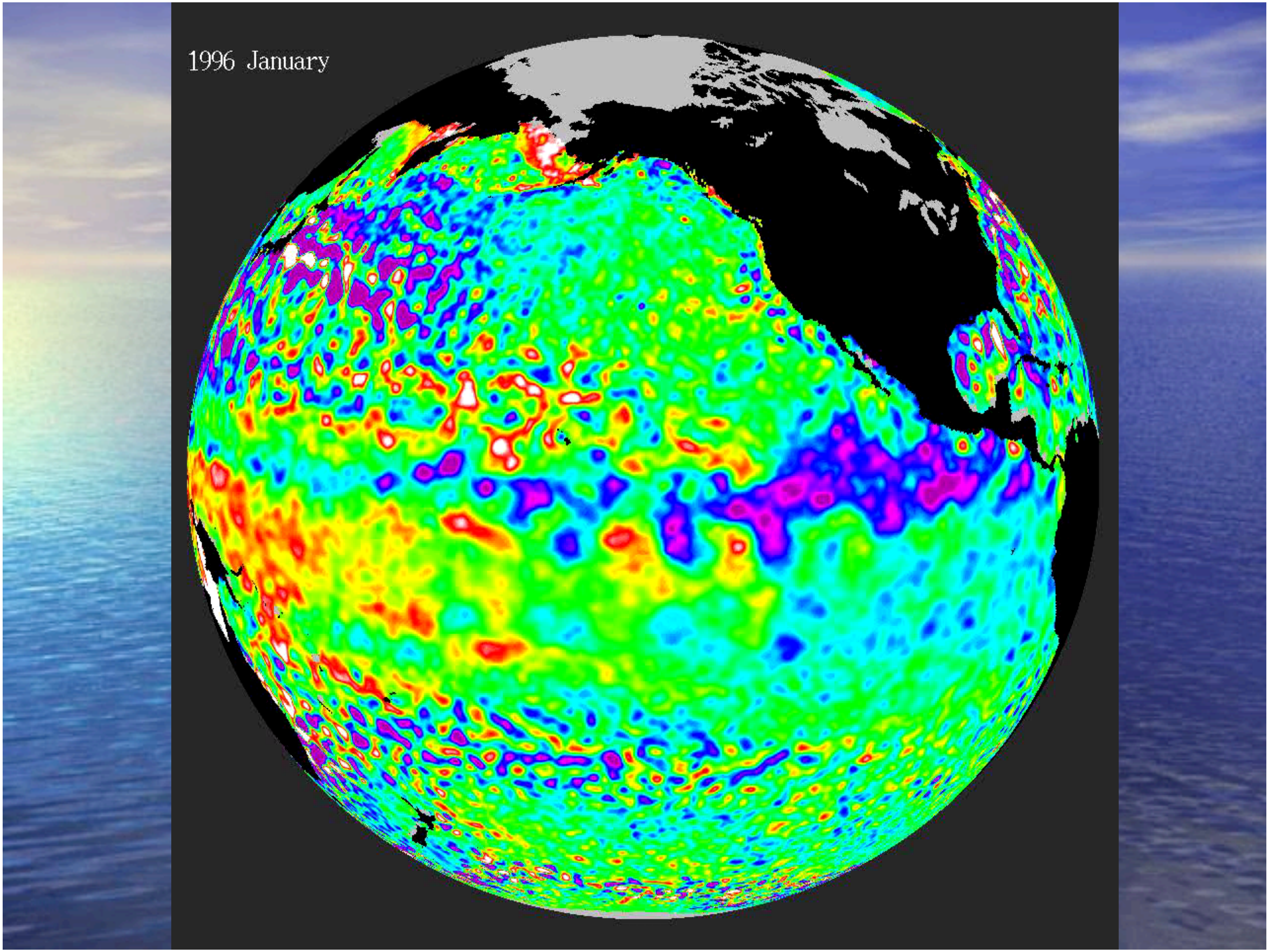


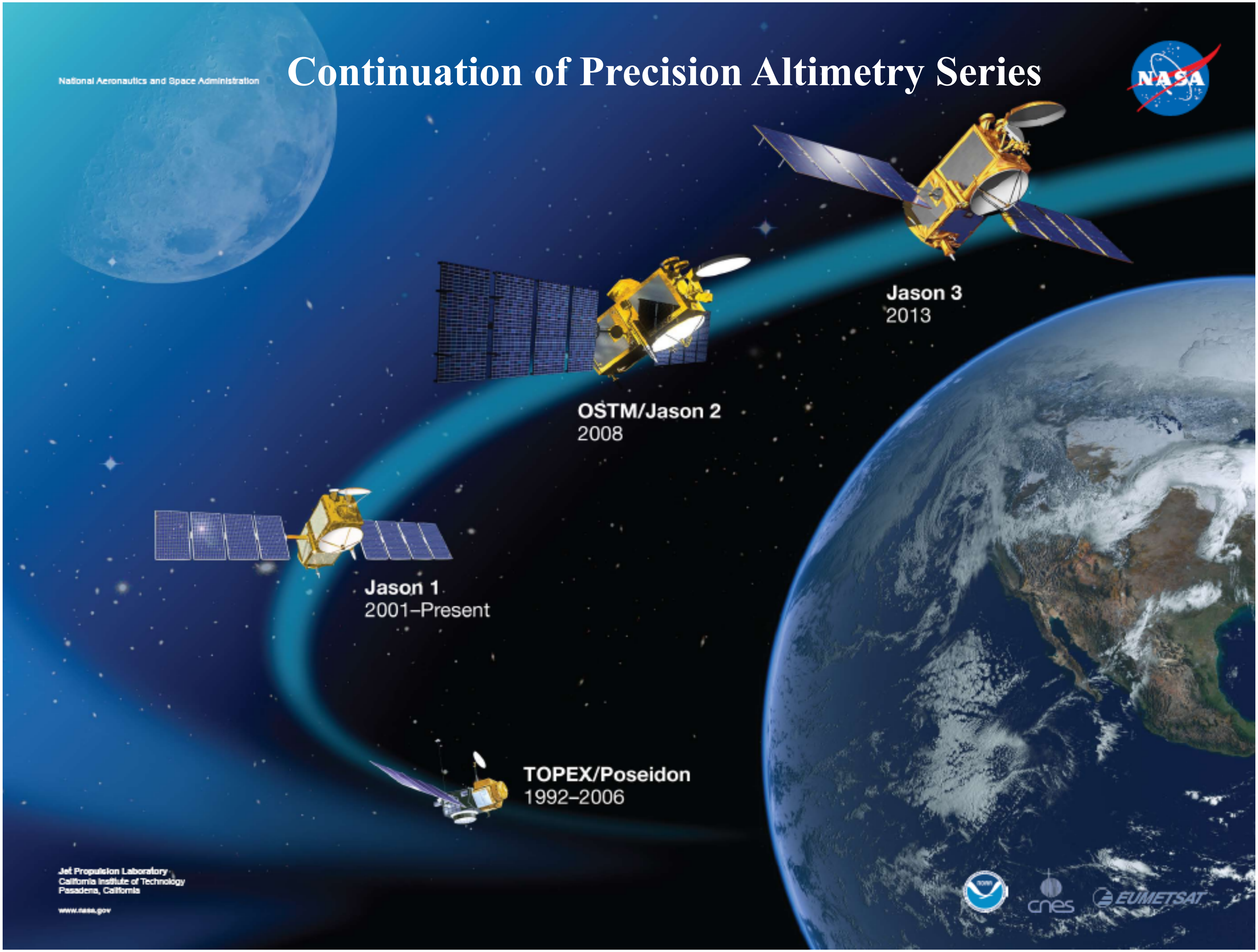
Maximenko et al, 2008

A Model Simulation

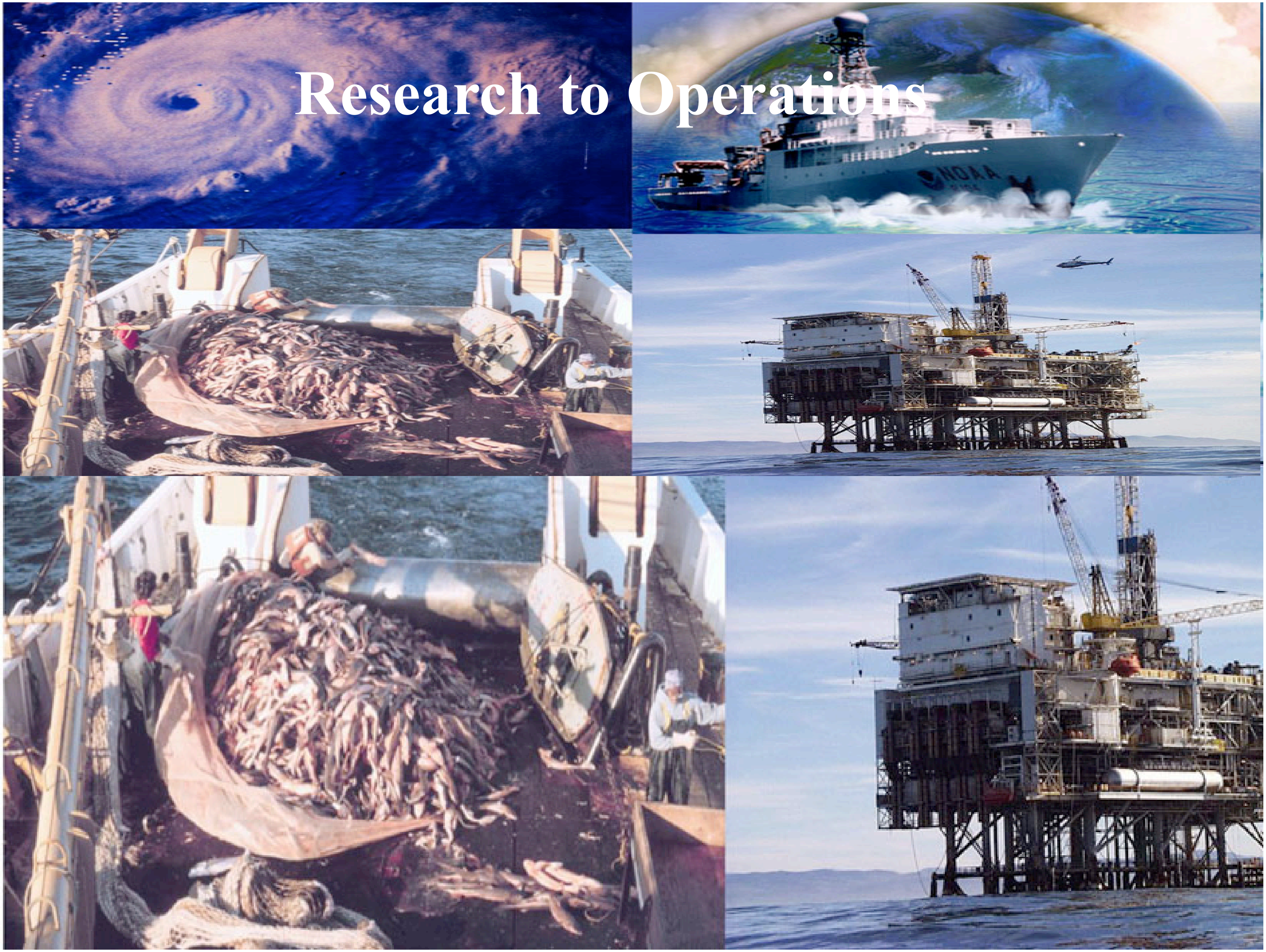


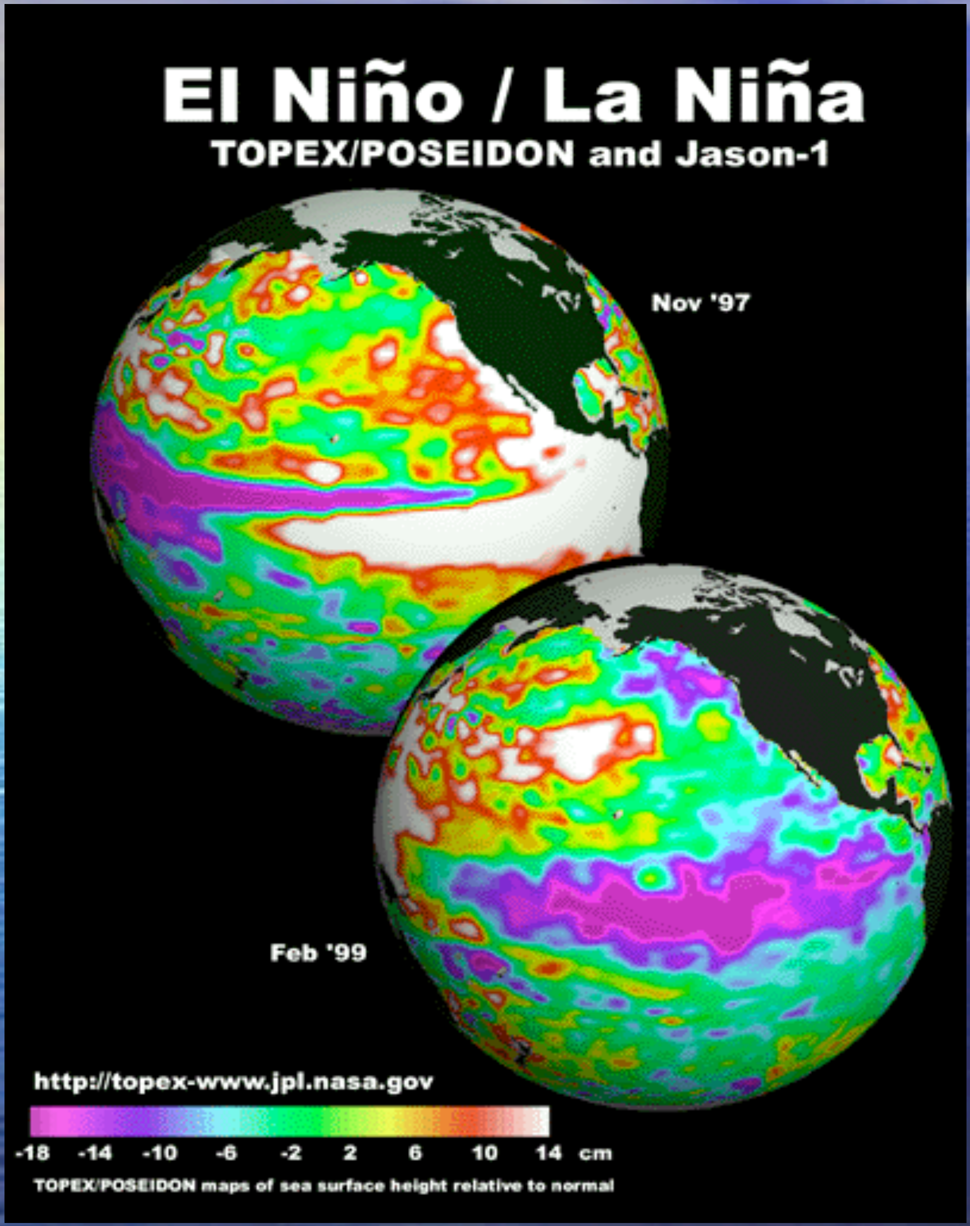
Richards et al, 2006

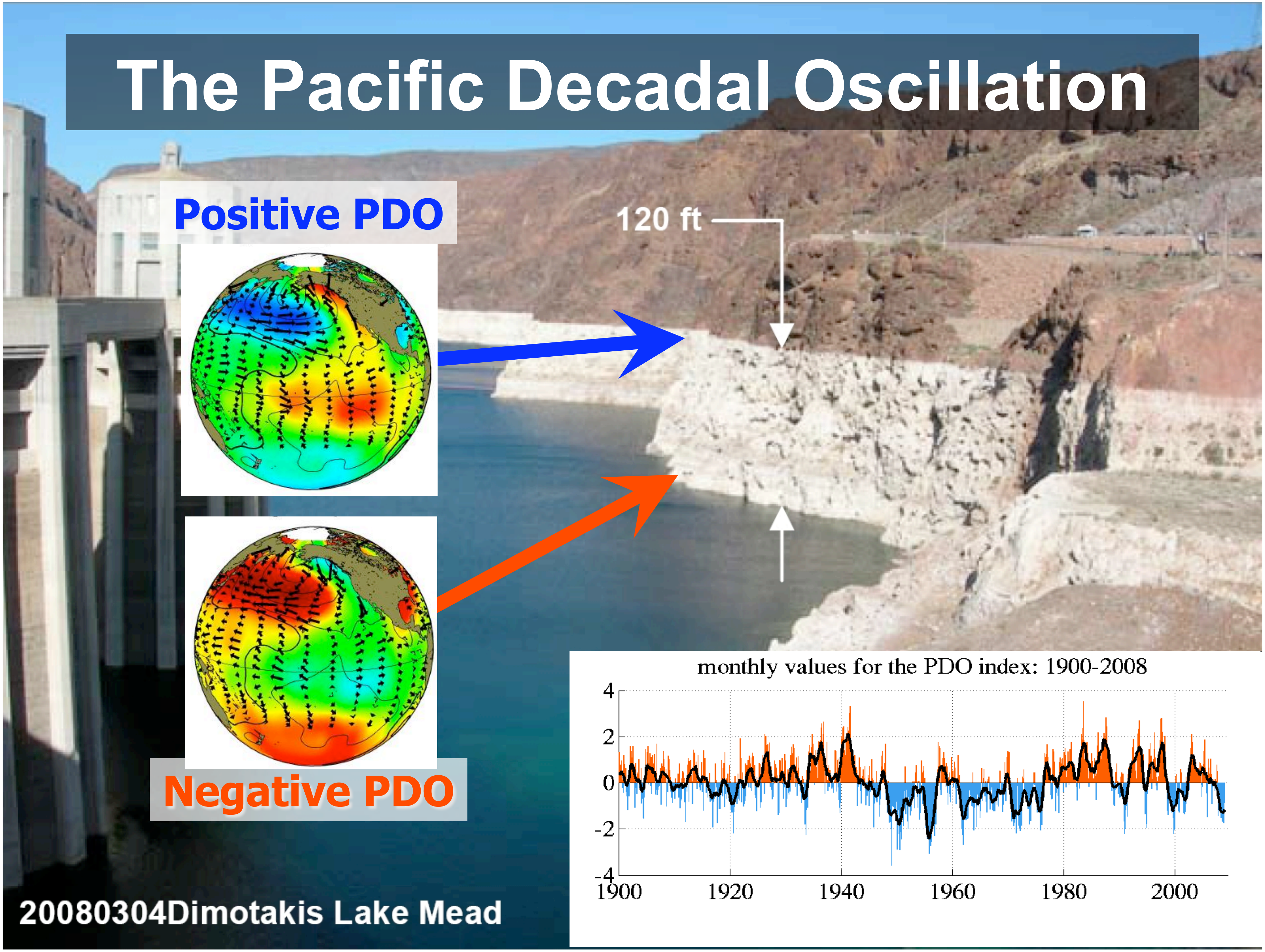

1996 January


National Aeronautics and Space Administration
Continuation of Precision Altimetry Series
NASA
Jason 3
2013
OSTM/Jason 2
2008
Jason 1
2001–Present
TOPEX/Poseidon
1992–2006
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov
cnes
EUMETSAT

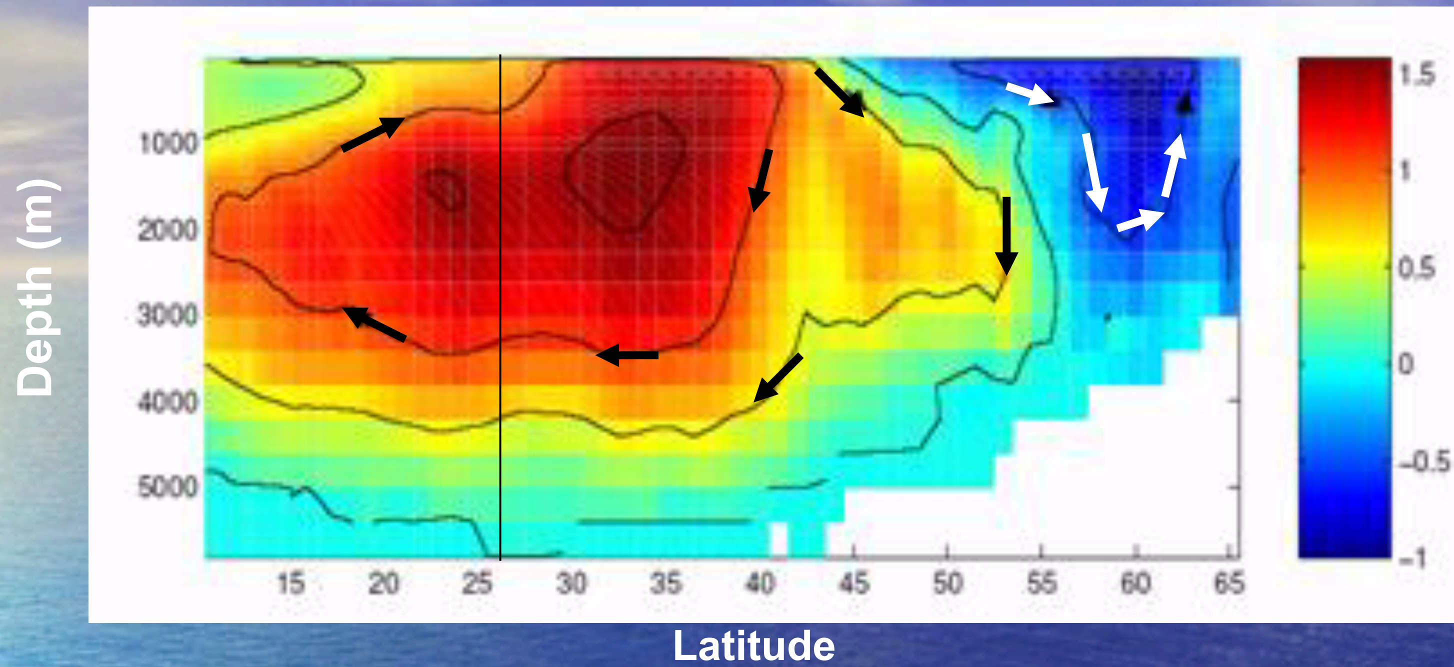
Research to Operations



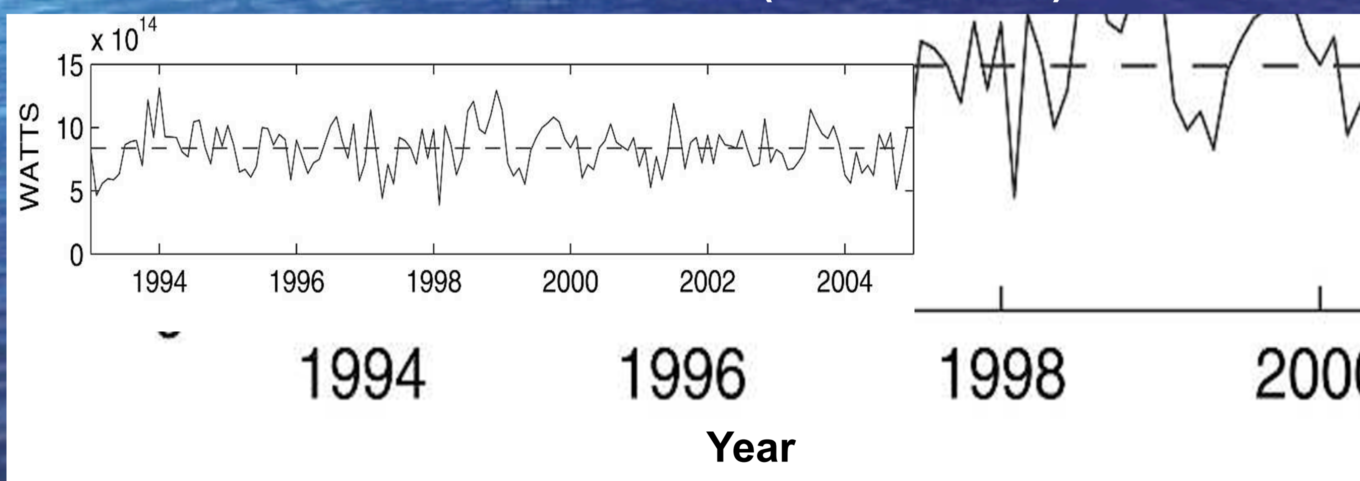

El Niño / La Niña
TOPEX/POSEIDON and Jason-1
Nov '97
Feb '99
http://topex-www.jpl.nasa.gov
-18 -14 -10 -6 -2 2 6 10 14 cm
TOPEX/POSEIDON maps of sea surface height relative to normal


The Pacific Decadal Oscillation
Positive PDO
120 ft
Negative PDO
monthly values for the PDO index: 1900-2008
4
2
0
-2
-4
1900
1920
1940
1960
1980
2000
20080304Dimotakis Lake Mead

The meridional overturning circulation of the North Atlantic (ECCO Analysis)



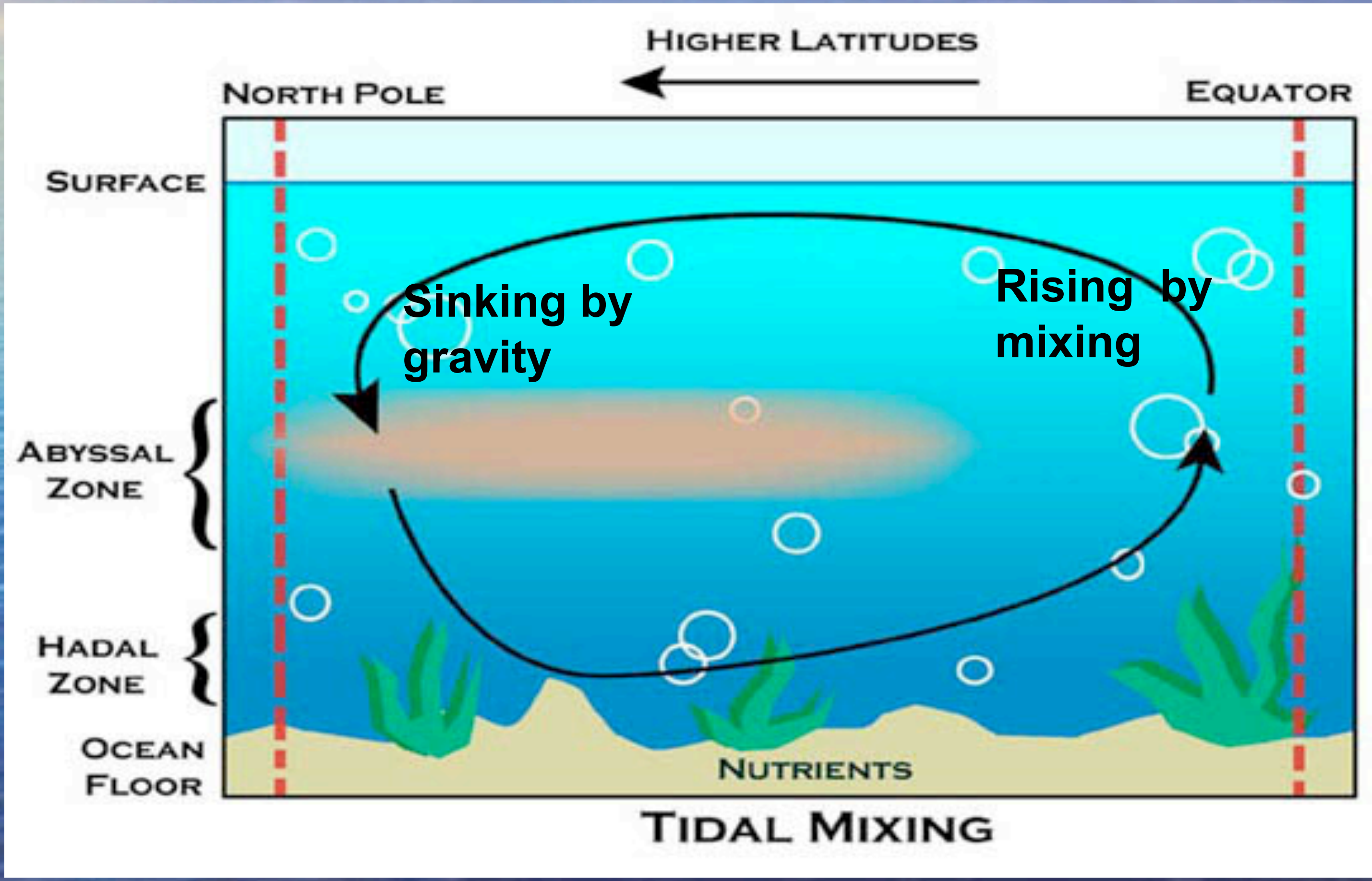
Northward Heat Flux (in 10^{14} watts) at 26º N

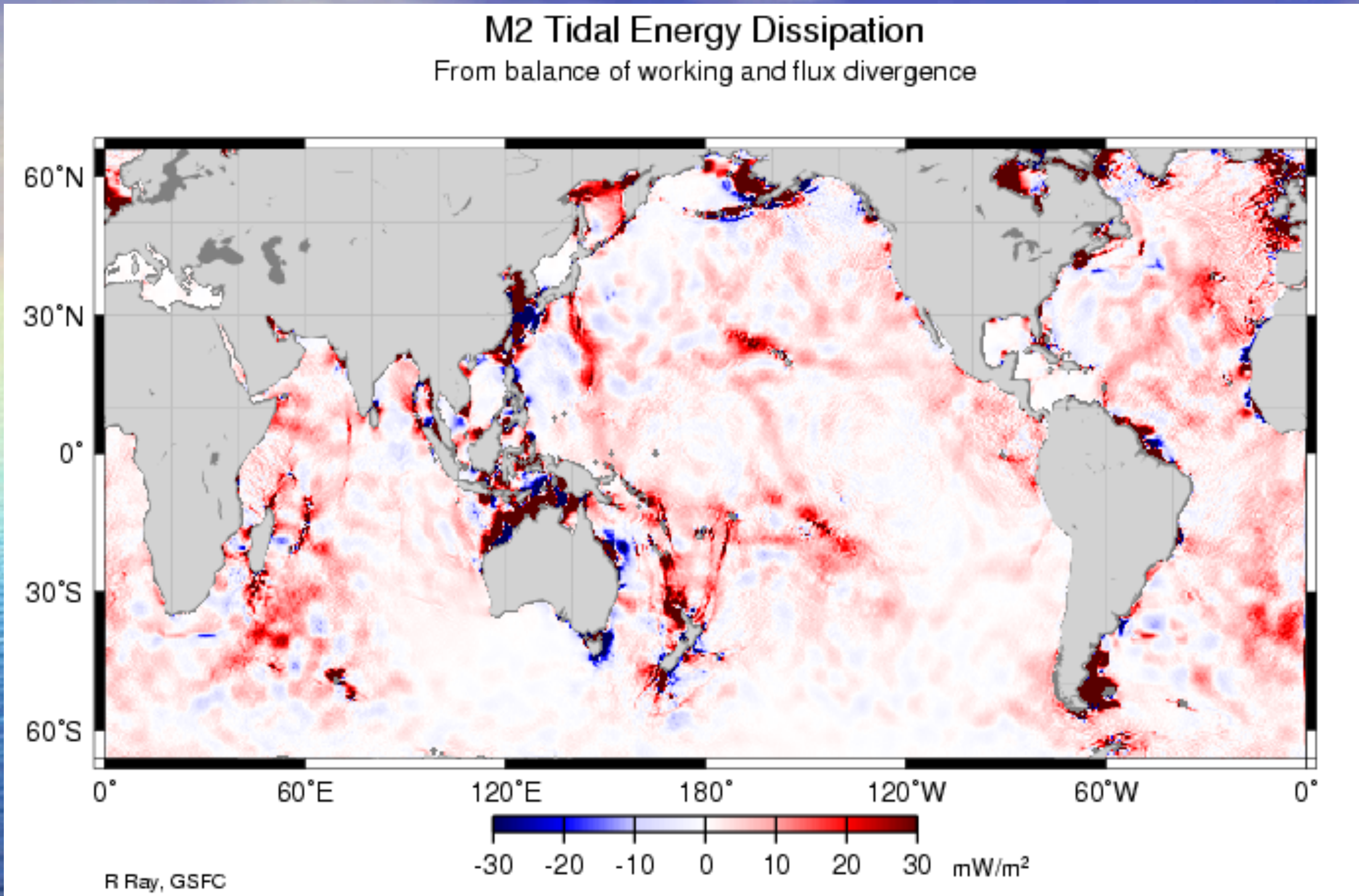


> 200 times of the US energy consumption rate

Wunch and Heimback, 2006

Reliable prediction of climate change requires breakthrough in understanding the vertical motion in the ocean

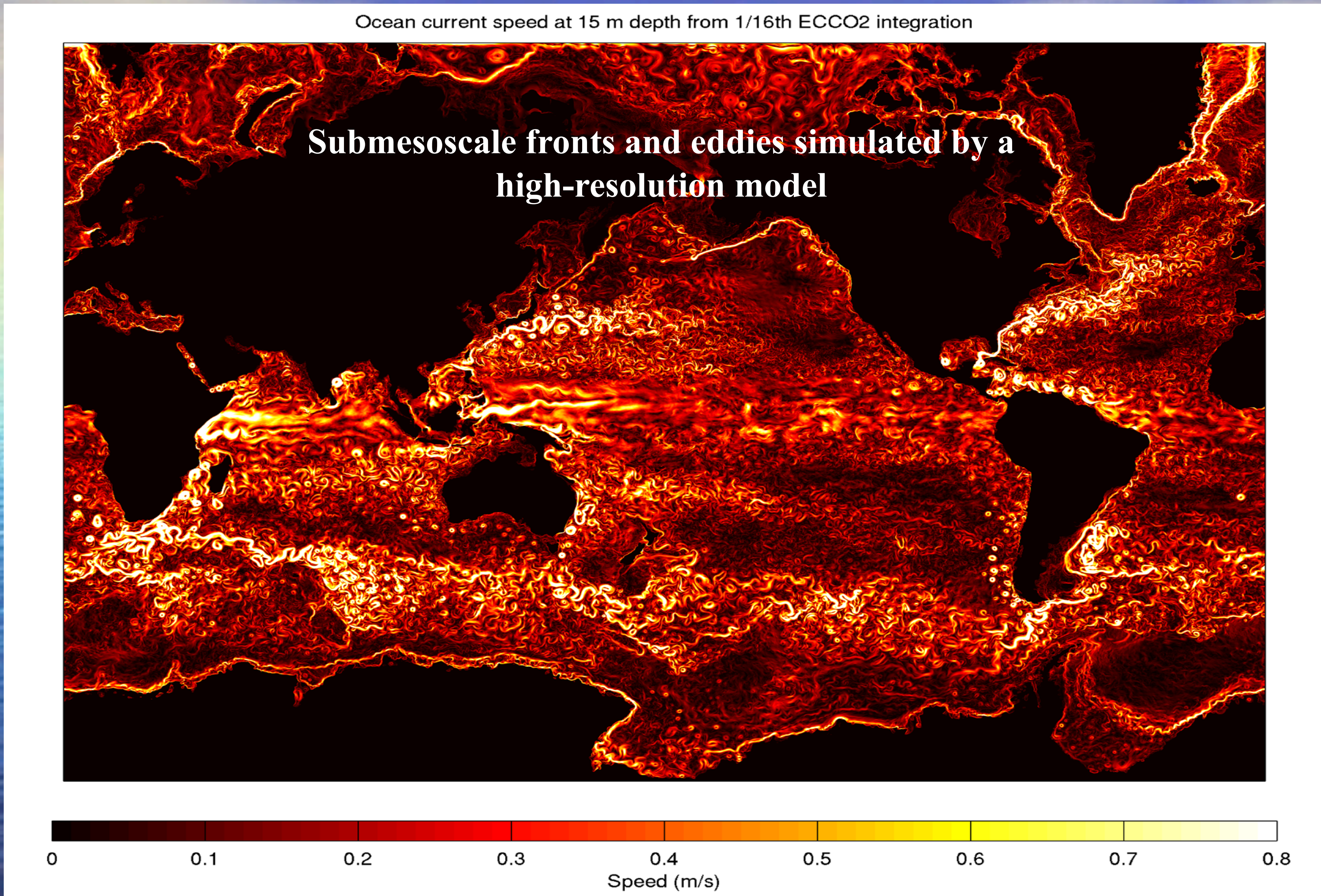




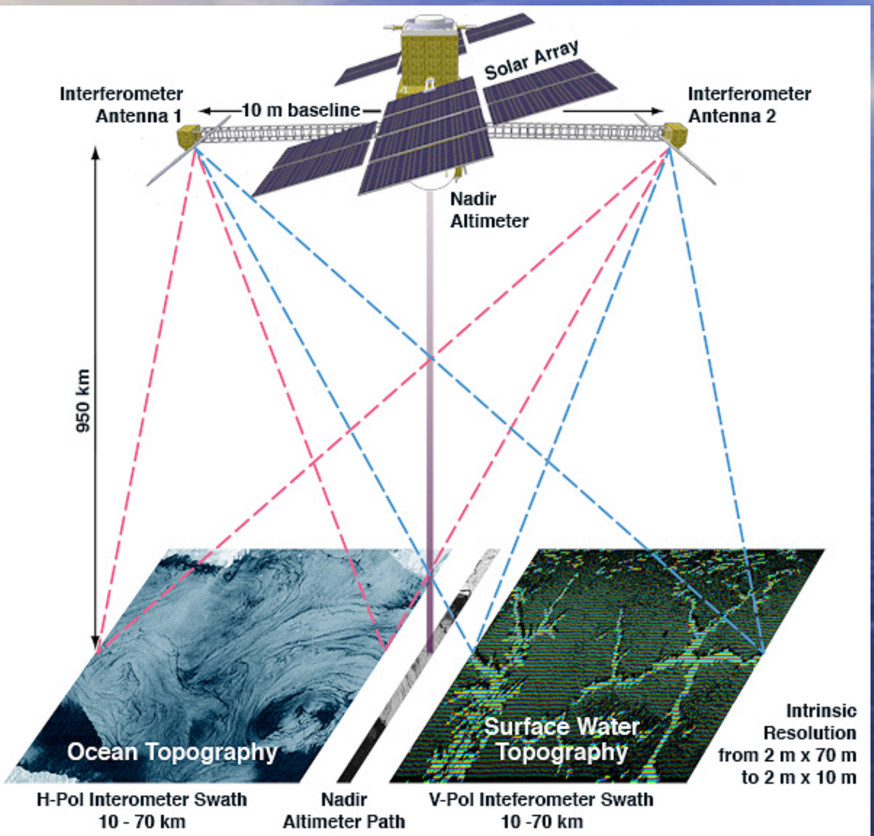
Total tidal dissipation= 1 TW (10^{12}) ~ 1/3 US energy consumption rate; half of total ocean mixing

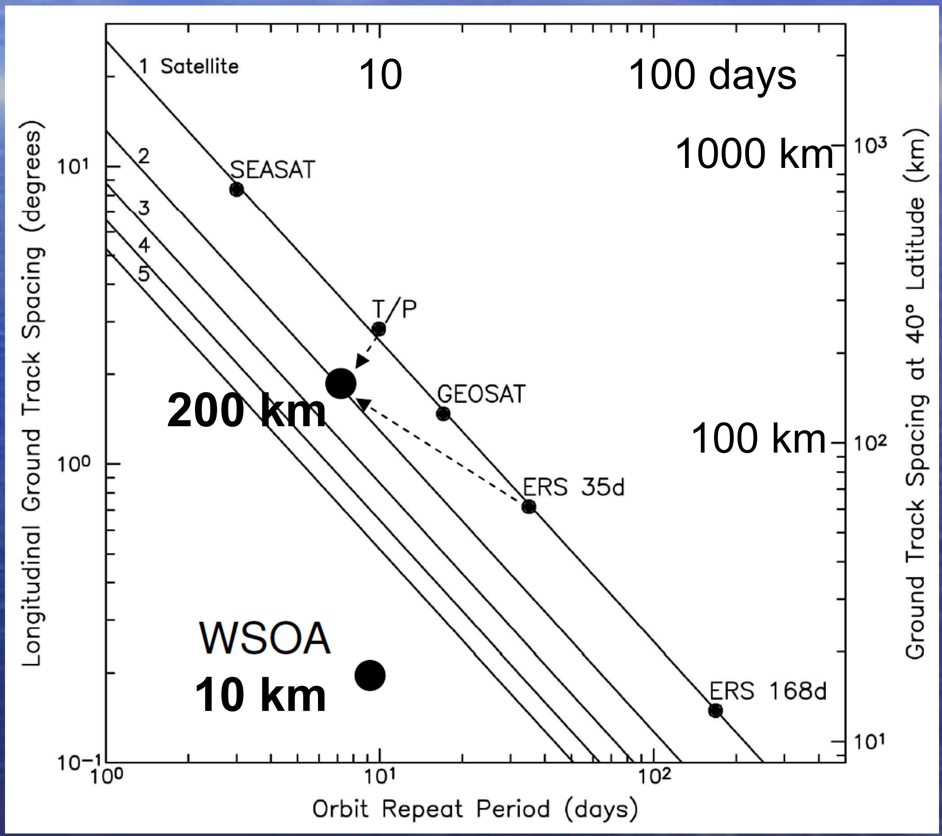
Egbert & Ray (2000)

Another 50% of the vertical motion and mixing takes place in the upper ocean at scales shorter than 100 km not yet observed.



High-resolution wide-swath altimetry will make breakthrough in observing the oceanic submesoscale



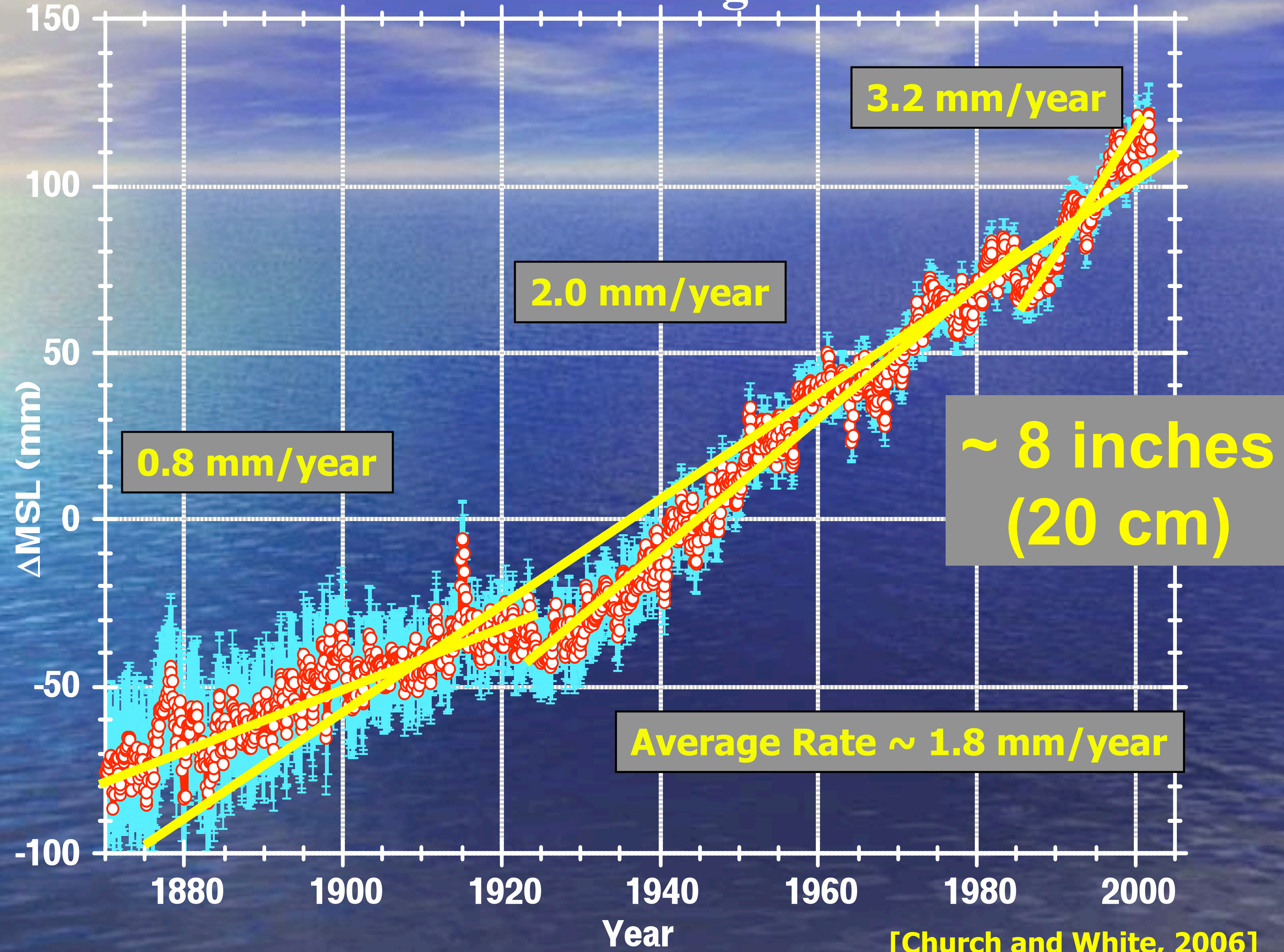


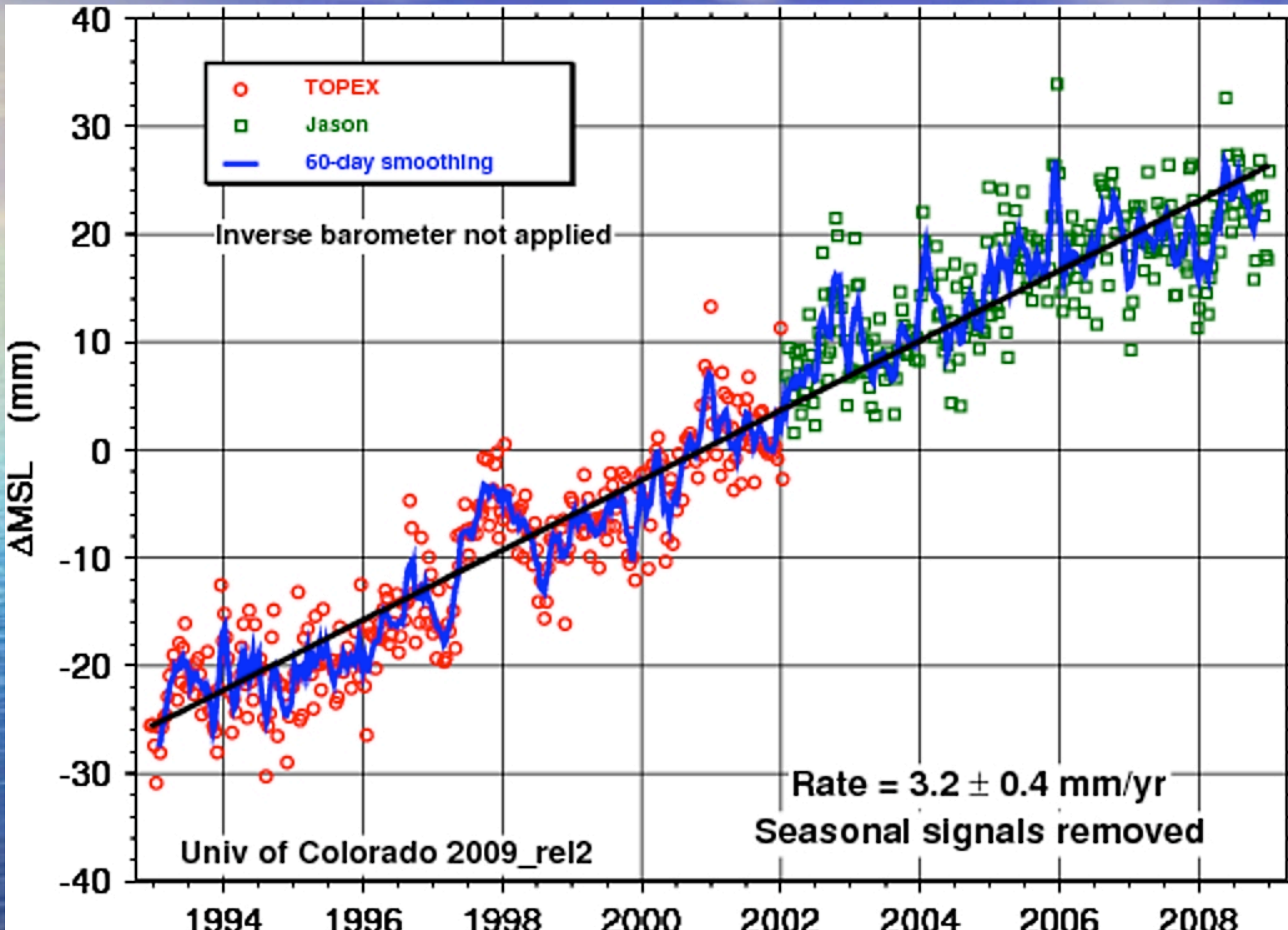
Surface Water & Ocean Topography (SWOT), a NASA/CNES mission recommended by the NRC Decadal Survey

SWOT

1 km

Sea Level Rise: a present and imminent impact of climate change

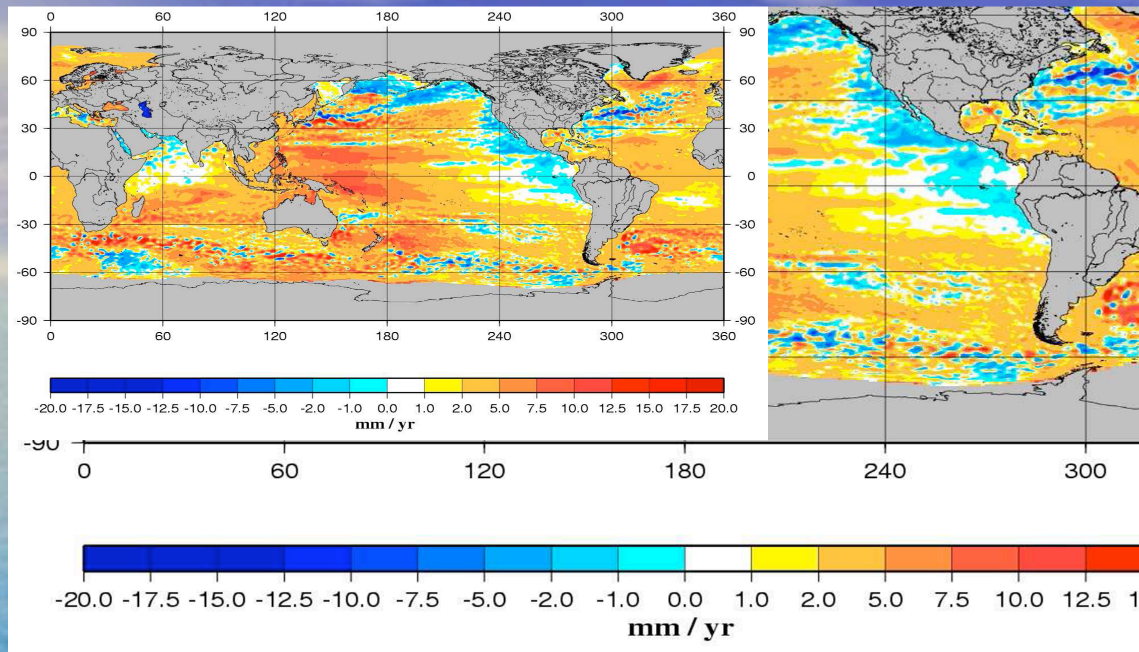




TOPEX
Jason
60-day smoothing
Inverse barometer not applied
ΔMSL (mm)
40
30
20
10
0
-10
-20
-30
-40
1994
1996
1998
2000
2002
2004
2006
2008
Rate = 3.2 ± 0.4 mm/yr
Seasonal signals removed
Univ of Colorado 2009_rel2

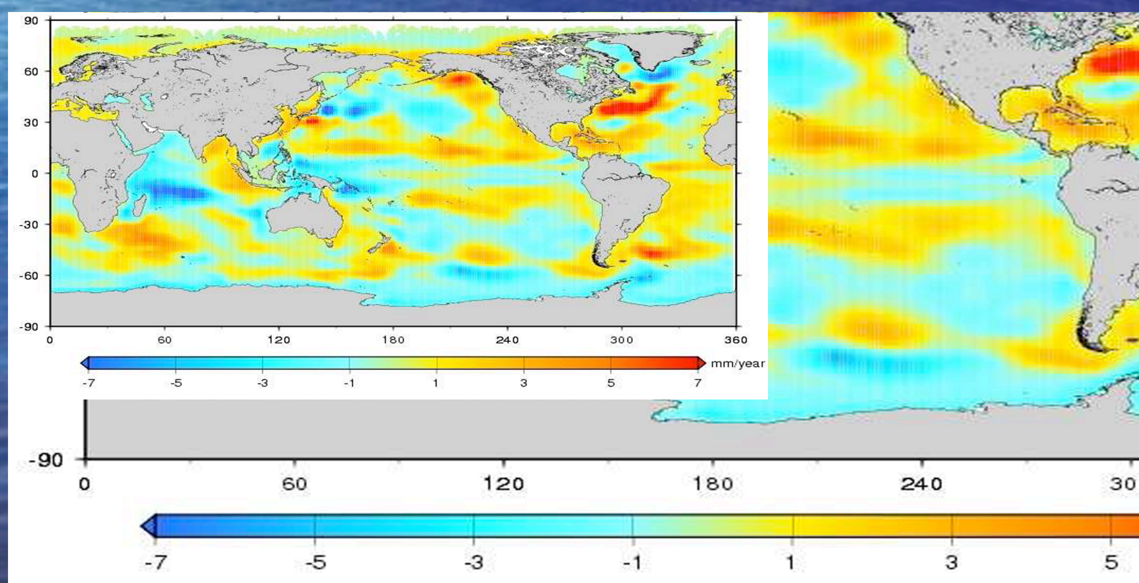
Nerem, 2009

Spatial Patterns of Global Sea Level Trend



1993-2008

From altimetry

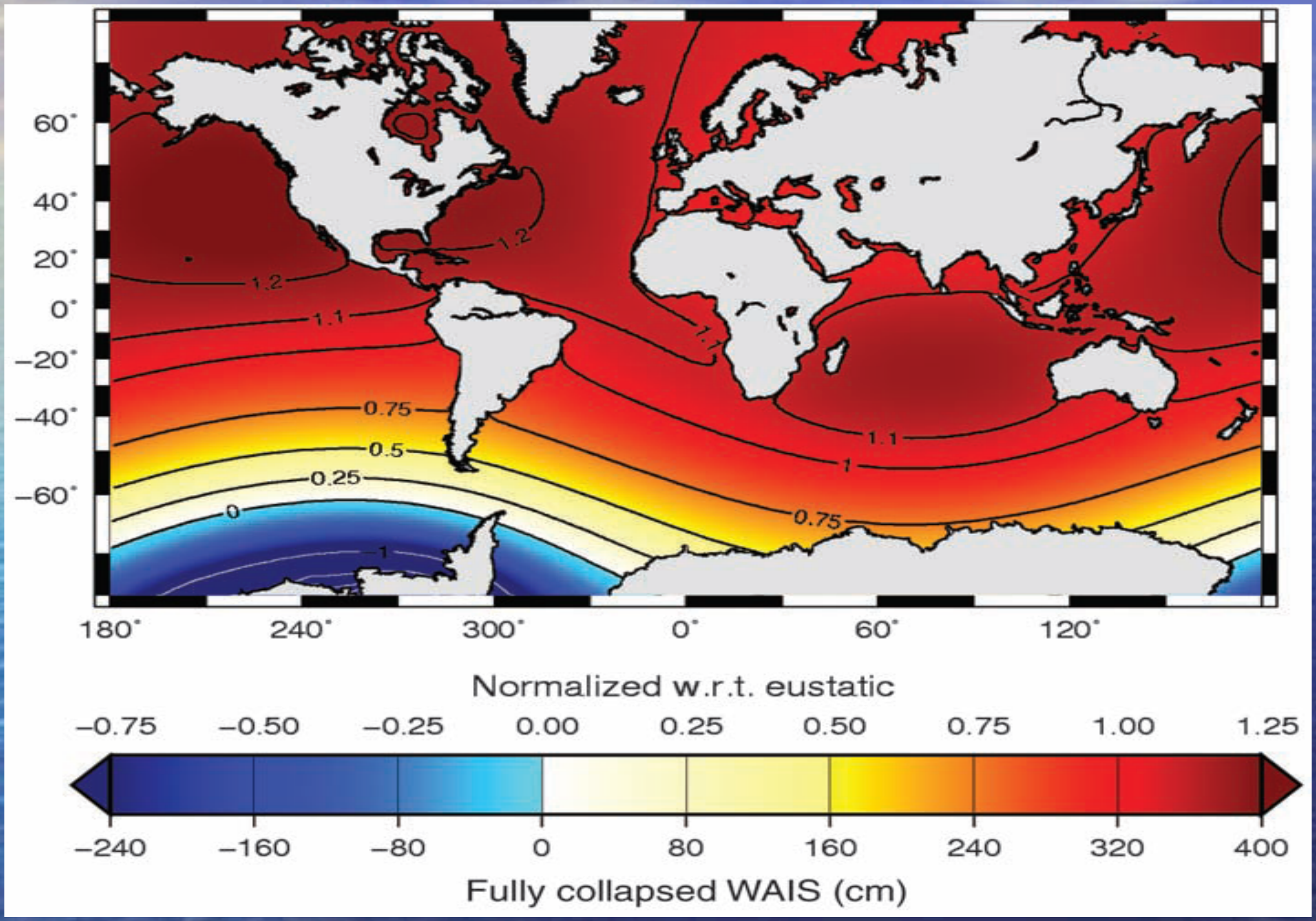


1950-2003

Reconstruction from tide gauges

Llovel et al, 2009

Sea level change after instantaneous removal of ice from the Western Antarctic Ice Sheet



A global average of 3.2 m, but the highest is around the US

Including the effects of self gravitation, elastic rebound of the lithosphere, and Earth rotation perturbations but excluding the effects of ocean circulation and other sources of ocean mass.

Bamber et al, 2009

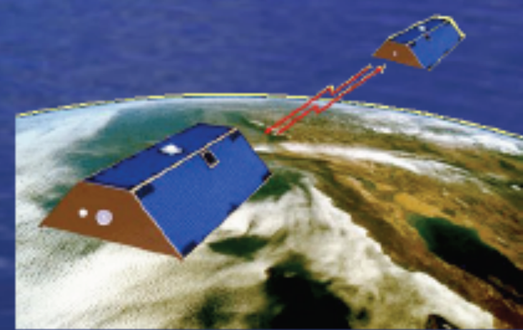
Combining Data to Study Sea Level Change

Addition of Heat

Argo

+

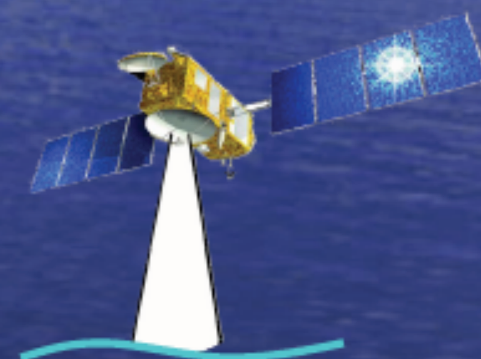
Addition of Freshwater



GRACE

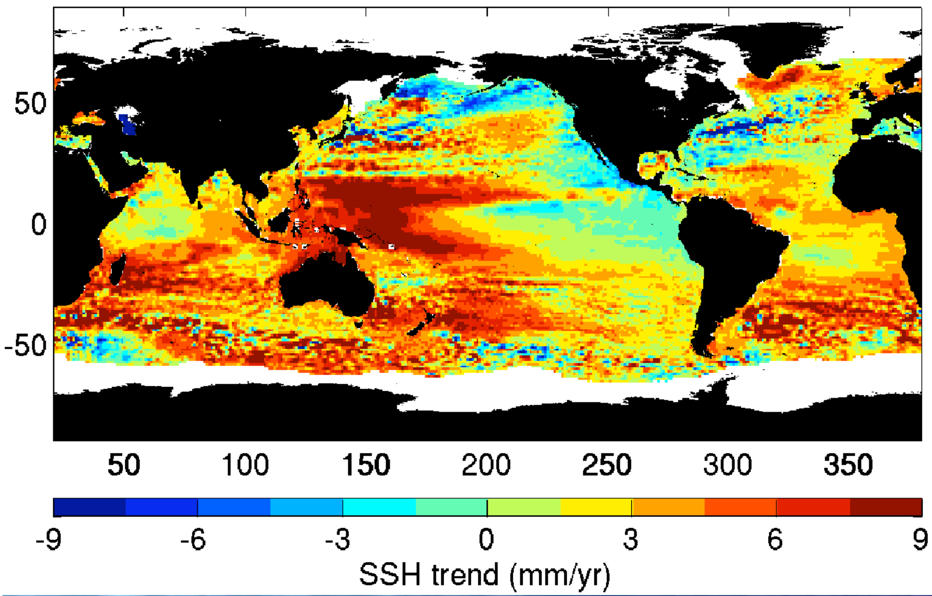
= (roughly)

Total Sea Level Rise

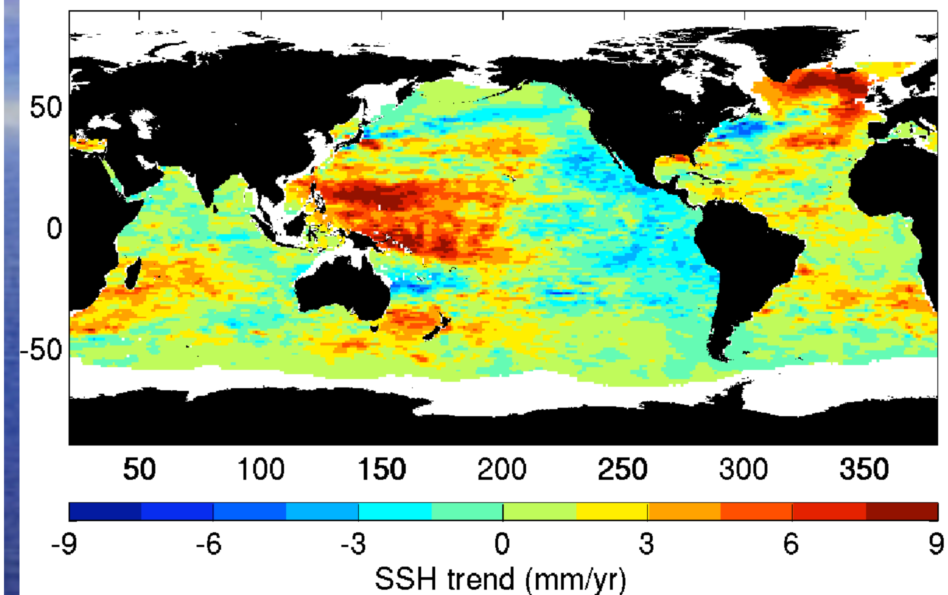


Jason

Observed Sea Level Trends: 1993-2008



Total Sea Level (Altimetry)

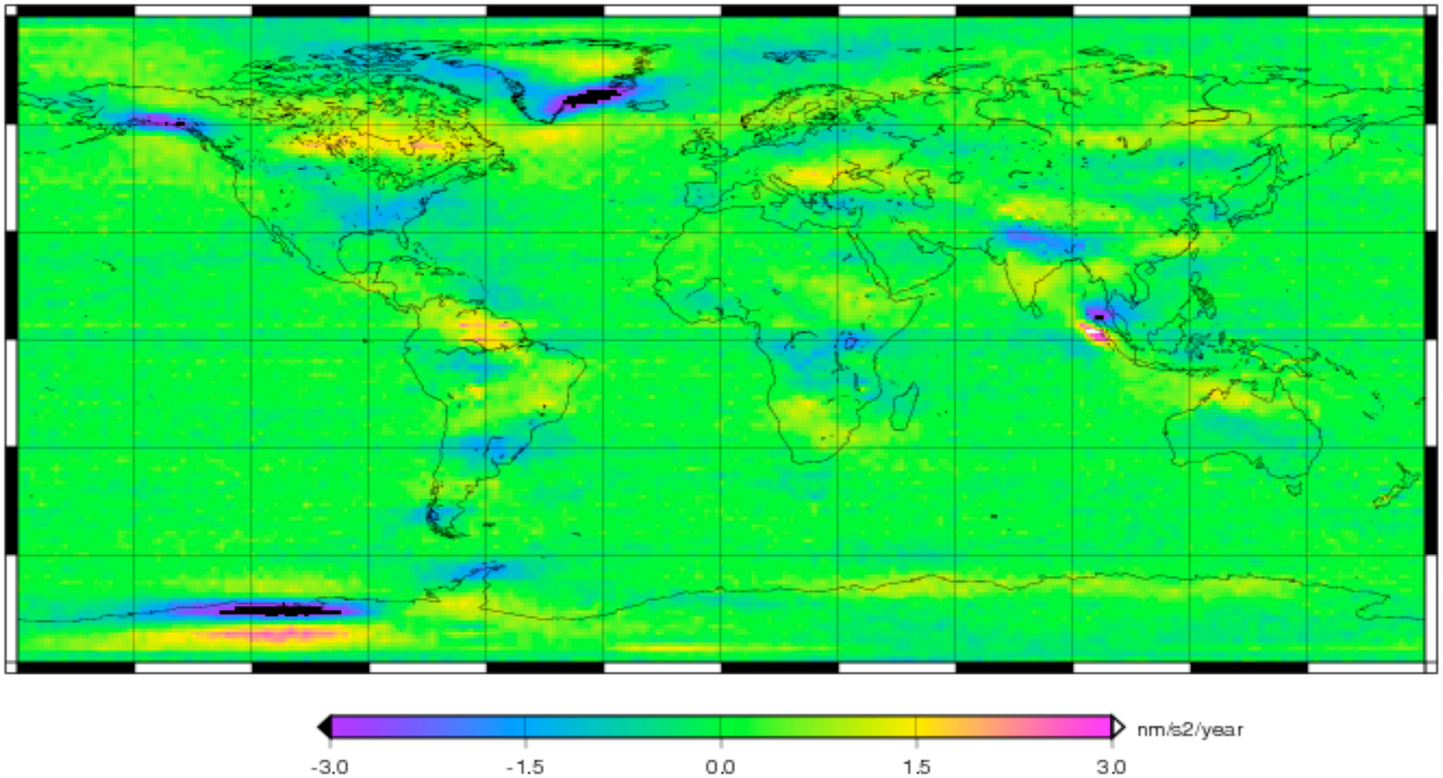


Thermosteric Sea Level (XBTs, Argo, etc..)

J. Willis/JPL

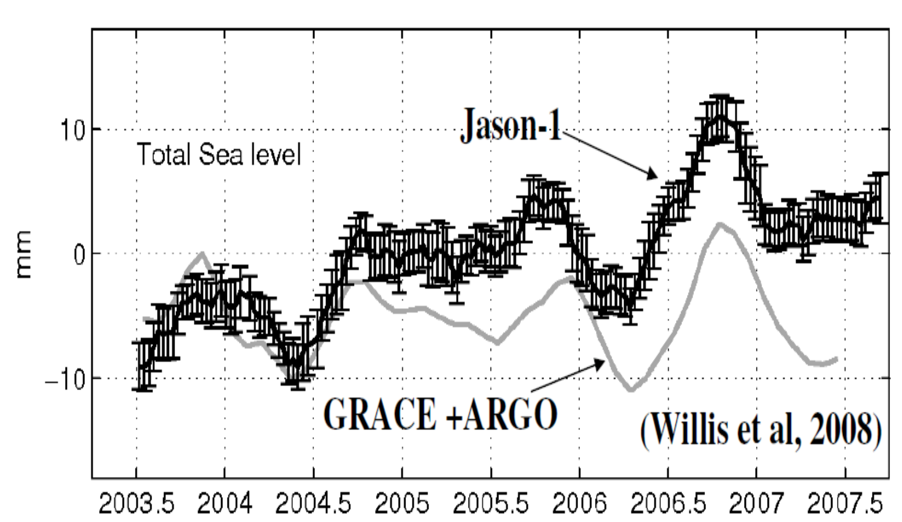
Global Surface Mass Trends Observed by GRACE 2002-2007

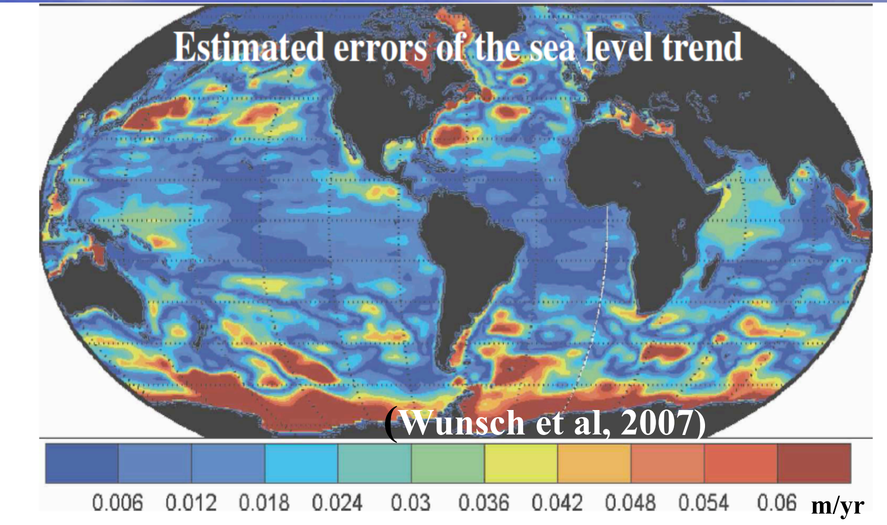
Note ice mass loss in Greenland, Antarctica, Alaska



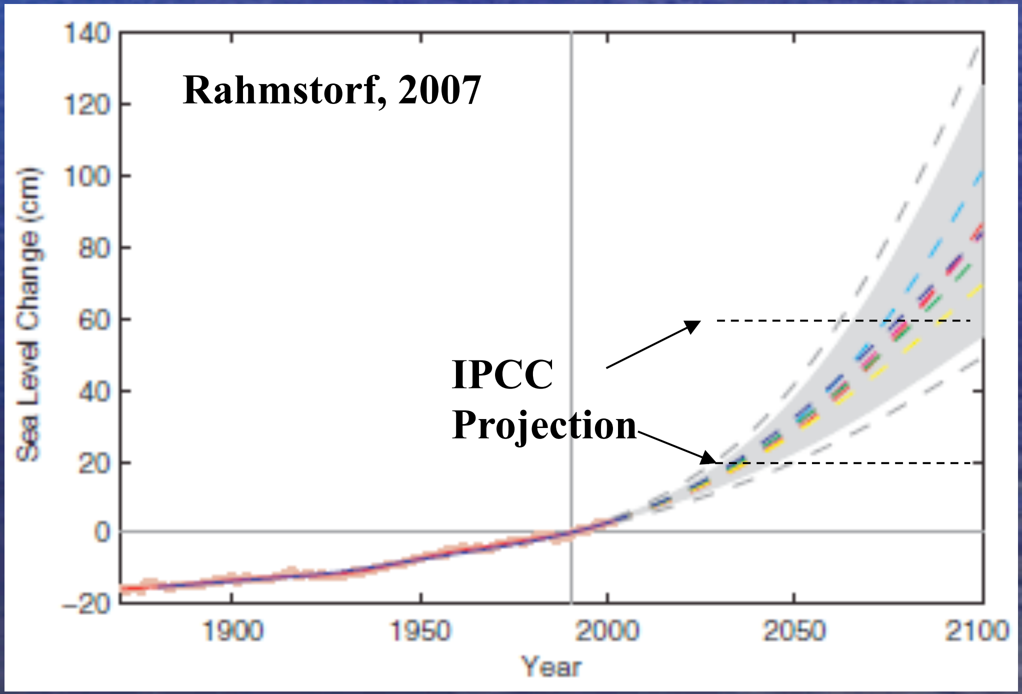
(Watkins, 2008)

Unknown systematic errors





Predicting sea level change is a complex, challenging, and long-term problem.



Closing Remarks

- Satellite altimetry has revolutionized the study of ocean circulation and sea level in relation to climate change.

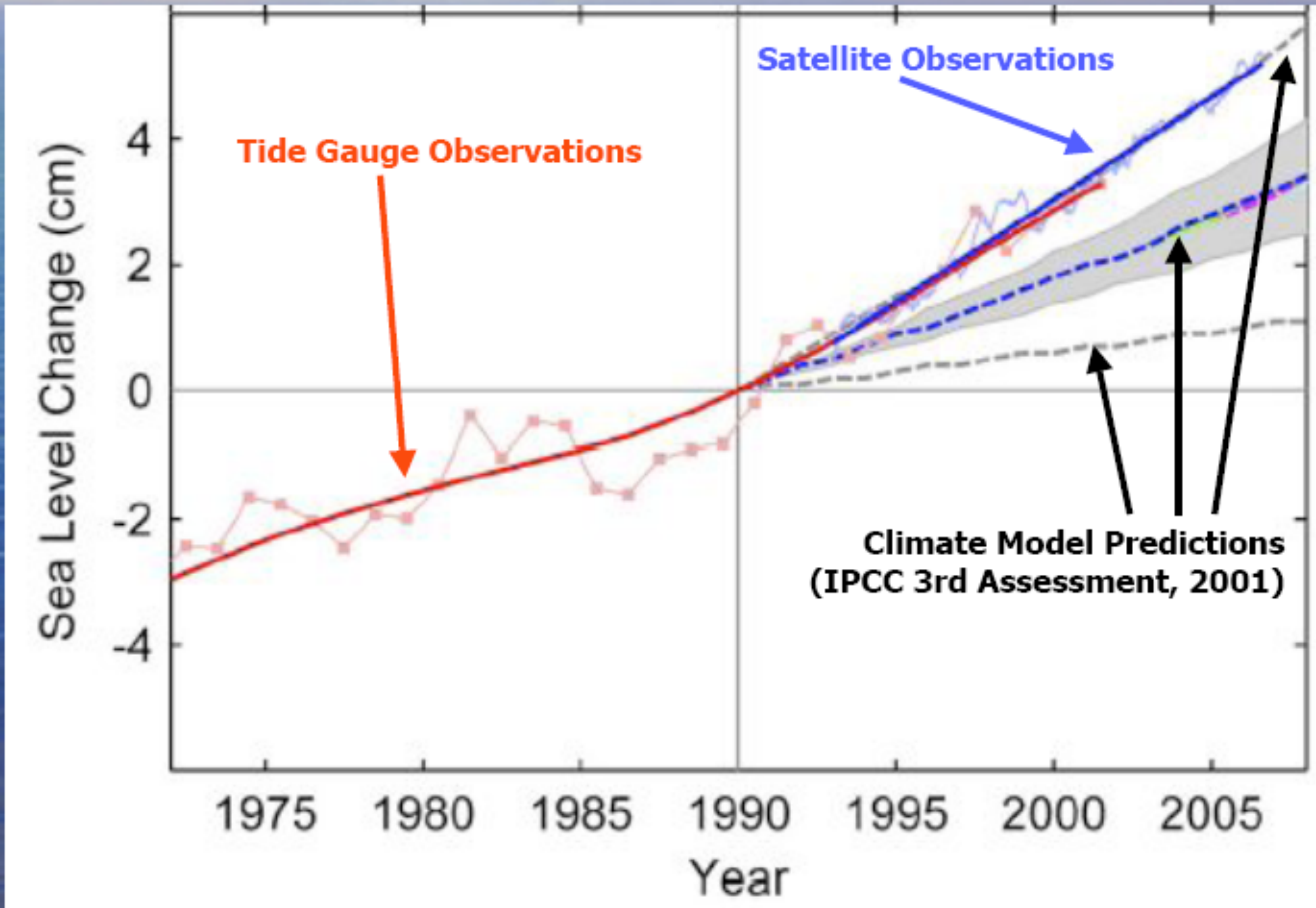
- Future challenges:

  - Observing the small-scale ocean currents that determine the ocean's capacity for regulating climate change.

  - Monitoring and predicting sea level change as a multidisciplinary problem (oceanography, meteorology, glaciology, geodesy, geodynamics, hydrology, etc).

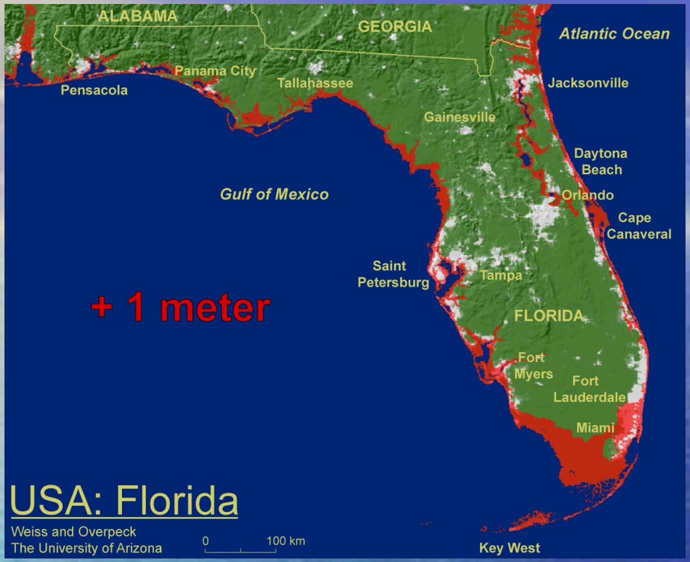
  - NASA is positioned to set an agency-level focus on tackling the sea level problem

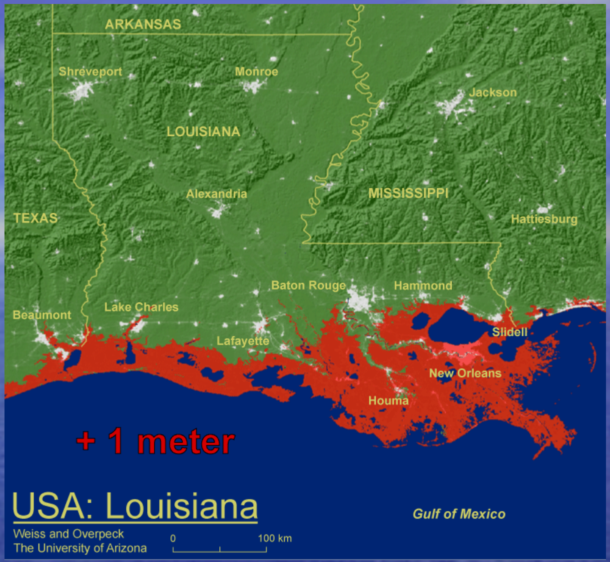
Sea Level Observations versus Predictions



[Rahmstorf et al., 2007

Coastal Impacts





Over 2.2 billion people live within 100 km of the coast!